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Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) Antarctic Ozone Atlas: August Through November 1991

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NIMBUS-7 TOMS ANTARCTIC OZONE ATLAS:
AUGUST THROUGH NOVEMBER 1991

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ABSTRACT

Because of the great environmental significance of stratospheric ozone and to support continuing research at the Antarctic and other Southern Hemisphere stations, the development of the 1991 ozone hole was monitored using data from the Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) instrument, produced in near-real-time. This atlas provides a complete set of daily polar orthographic projections of the TOMS total ozone measurements over the Southern Hemisphere for the period August 1 through November 30, 1991. The 1991 ozone hole developed in a manner similar to that of 1987, 1989 and 1990, reaching a comparable depth in early October. However, the 1991 ozone hole filled far more rapidly than in 1987 or 1989, and nearly 4 weeks earlier than in 1990. Daily ozone values above selected Southern Hemisphere stations are presented, along with a time series of monthly means above these stations. Comparisons of the 1991 ozone hole event with those of previous years are also presented.

1. INTRODUCTION

Intensive ground-based (Komhyr et al., 1989) and satellite observations (Krueger et al, 1988a) have revealed a continuing downward trend in the total column ozone amounts over Antarctica, as well as a gradual decrease in global ozone amounts (Herman et al., 1991). This decrease, which occurs seasonally during September and October, has resulted in a depletion in the column ozone amounts by as much as 50%. The interannual variability is related to changes in atmospheric dynamics (Schoeberl and Hartmann, 1991) as well as chemical changes (Anderson, 1991). The Antarctic ozone minimum, termed "the ozone hole", reached the lowest values observed to that point in 1987 (Krueger et al., 1988a). The 1988 ozone hole was displaced from the South Pole and far weaker than in 1987 (Krueger et al., 1989). However, the 1989 ozone hole was comparable to the 1987 event (Krueger et al., 1990). The 1990 ozone hole seemed to break a trend which had seen the lowest polar ozone values during the odd-numbered years. Values during the 1990 event were comparable to those of 1987 and 1989. The 1991 ozone hole saw the lowest polar ozone values to date (Krueger, et al., 1992). However, the 1991 ozone hole event differed from those of 1987, 1989 and 1990 by dissipating three to four weeks earlier.

1.1 1991 Antarctic Ozone Monitoring

Following the dramatic decline in total ozone over the Southern Hemisphere observed during the 1987 Airborne Antarctic Ozone Experiment, it was decided to gather, in near-real-time, hemispheric total ozone during the same period in 1988. Since 1988, the development and disintegration of the Antarctic ozone hole has been monitored in near-real-time, with the data widely disseminated to researchers worldwide.

An atlas of the TOMS coverage of the 1987 ozone hole and background information on the Nimbus-7 TOMS experiment, as well as the processing used to produce hemispheric total ozone contour plots may be found in Krueger, et al. (1988b). Details of the project operations and the communications network used in the 1987 ozone expedition can be found in Ardanuy, at al. (1988). An atlas of the TOMS coverage of the 1988 ozone hole may be found in Krueger, et al. (1989), of the 1989 ozone hole in Krueger, et al. (1990) and of the 1990 ozone hole in Krueger, et al. (1991). ASCII and image data are available on CD-ROM.

1.2 TOMS Data Version

The 1990 ozone atlas presented TOMS total ozone values produced using an updated calibration scheme, Version 6. Version 6 data have also been used to produce this document. It should be noted that the TOMS total ozone values produced in near-real-time do not contain the most up-to-date calibration coefficients, and differ slightly from the production data presented in this atlas. This difference approaches 4 percent and depends on time and latitude of the real-time data.

2. TOMS TOTAL OZONE DATA

2.1 Chronology of the 1991 Antarctic Ozone Hole

AUGUST 18, 1991

This is the first day for which a TOMS hemispheric image is obtained in near-real-time. The lowest polar ozone values are between 200 and 225 Dobson Units (DU) and are located near the terminator over Wilkes Land and in several mini-holes to the east and west of the Antarctic peninsula.

AUGUST 23, 1991

A significant mini-hole with total ozone values below 175 DU has developed over the Antarctic Peninsula. A small ozone maxima exists south of Australia with total ozone values in excess of 475 DU.

AUGUST 26, 1991

The Southern Hemisphere winter polar minimum is developing and is relatively circular, with three local minima symmetrically distributed about the pole. The lowest total ozone values in these minima are near or slightly below 200 DU.

AUGUST 30, 1991

Another significant mini-hole has developed as one of the local minima has rotated over the Antarctic Peninsula. Lowest total ozone values here are between 150 and 175 DU.

SEPTEMBER 1, 1991

An extension of the polar minimum reaches northward toward South America. Total ozone values fall below 225 DU over Cape Horn. Closer to the pole, a growing area of total ozone values between 175 and 200 DU exists over the Antarctic coast from the Amundsen Sea to western Queen Maude Land.

SEPTEMBER 4, 1991

A large ozone maximum with total ozone values above 525 DU is moving through the Indian Ocean south of Australia. This has moved the polar ozone minimum away from the pole. Minimum total ozone values are between 175 and 200 DU over Queen Maude Land and the Antarctic Peninsula.

SEPTEMBER 8, 1991

The ozone maximum has rotated eastward and dissipated. The polar ozone distribution has become more circular and symmetric with the pole. Total ozone values below 225 DU now encircle the pole, and a large area of total ozone between 175 and 200 DU exists over Antarctica from The Ross Sea eastward to western Queen Maude Land.

SEPTEMBER 11, 1991

Total ozone values below 200 DU now nearly encircle the pole, extending northward to 60°S latitude over the South Sandwich Islands. Several small areas of total ozone values between 150 and 175 DU exist.

SEPTEMBER 13, 1991

The ozone hole has elongated and is rotating in response to a large maximum with total ozone values in excess of 500 DU over the southwest Indian Ocean. A growing area of total ozone values between 150 and 175 DU is located over Queen Maude Land.

SEPTEMBER 15, 1991

The ozone hole, deepening rapidly, now contains a growing area of total ozone values between 125 and 150 DU over western Queen Maude Land. The hole is elongated and pushed off the pole by an ozone maximum in excess of 525 DU north of Wilkes Land.

SEPTEMBER 19, 1991

The elongated ozone hole continues to rotate in response to the now weakening ozone maximum over the South Pacific. Total ozone values below 150 DU now nearly encircle the pole, with small areas between 125 and 150 DU near the pole.

SEPTEMBER 21, 1991

The ozone hole is now quite symmetric about the pole, with an extension toward South America. Total ozone values below 200 DU extend to Cape Horn. Values below 125 DU now encircle the pole.

SEPTEMBER 26, 1991

A large ozone maximum with total ozone values above 500 DU over the Indian Ocean has again elongated the ozone hole and pushed it off the pole.

SEPTEMBER 30, 1991

The ozone hole has become more circular with nearly 50 percent of the Antarctic continent covered by total ozone values between 125 and 150 DU.

OCTOBER 3, 1991

Despite strong elongation along longitudes 90°W/90°E, total ozone values below 125 DU appear near the pole.

OCTOBER 5, 1991

The ozone hole, symmetric about the pole and slightly elongated, reaches its minimum depth of 108 DU. A small area centered at the pole contains total ozone values between 108 and 125 DU.

OCTOBER 9, 1991

Total ozone values below 125 DU disappear for this season. An ozone maximum with a large area of total ozone values above 500 DU over the southeast Atlantic and southwest Indian oceans has severely elongated the ozone hole. Total ozone values below 200 DU again reach Cape Horn.

OCTOBER 14, 1991

The somewhat less elongated ozone hole continues to rotate as the ozone maximum moves to the southeast Indian Ocean. Total ozone values between 125 and 150 DU now cover roughly one-quarter of the Antarctic continent.

OCTOBER 19, 1991

A large ozone maximum with values above 500 DU over coastal Wilkes Land has pushed the ozone hole off the pole, although it retains its circular shape. Total ozone values now exceed 150 DU throughout the polar region.

OCTOBER 26, 1991

Although the lowest total ozone values are still below 175 DU over a significant area, the area with values below 275 DU is shrinking rapidly. The hole continues to reside off the pole with lowest values near the Weddell Sea.

OCTOBER 31, 1991

A large ozone maximum extending from coastal Wilkes Land to the South Pacific has pushed the ozone hole well off the pole. A very small area with total ozone values below 175 DU exists over Queen Maude Land. The ozone hole is elongated and extends northward to Argentina.

NOVEMBER 6, 1991

The area covered by total ozone values below 275 DU has shrunk to an area roughly the size of the Antarctic continent. It is centered along the coast of Queen Maude Land with a small area of total ozone values between 175 and 200 DU.

NOVEMBER 11, 1991

The center of the ozone hole is near the pole once again, but it is elongated along 160°W/20°E. A significant area of total ozone values below 200 DU persists.

NOVEMBER 15, 1991

The severely elongated ozone hole is filling rapidly. For the first time since August 21, total ozone values are above 200 DU throughout the Southern Hemisphere. A very narrow strip of values between 200 and 225 DU extends from southeast Pacific to Queen Maude Land. Total ozone values above 325 DU now cover half of the Antarctic continent

NOVEMBER 17, 1991

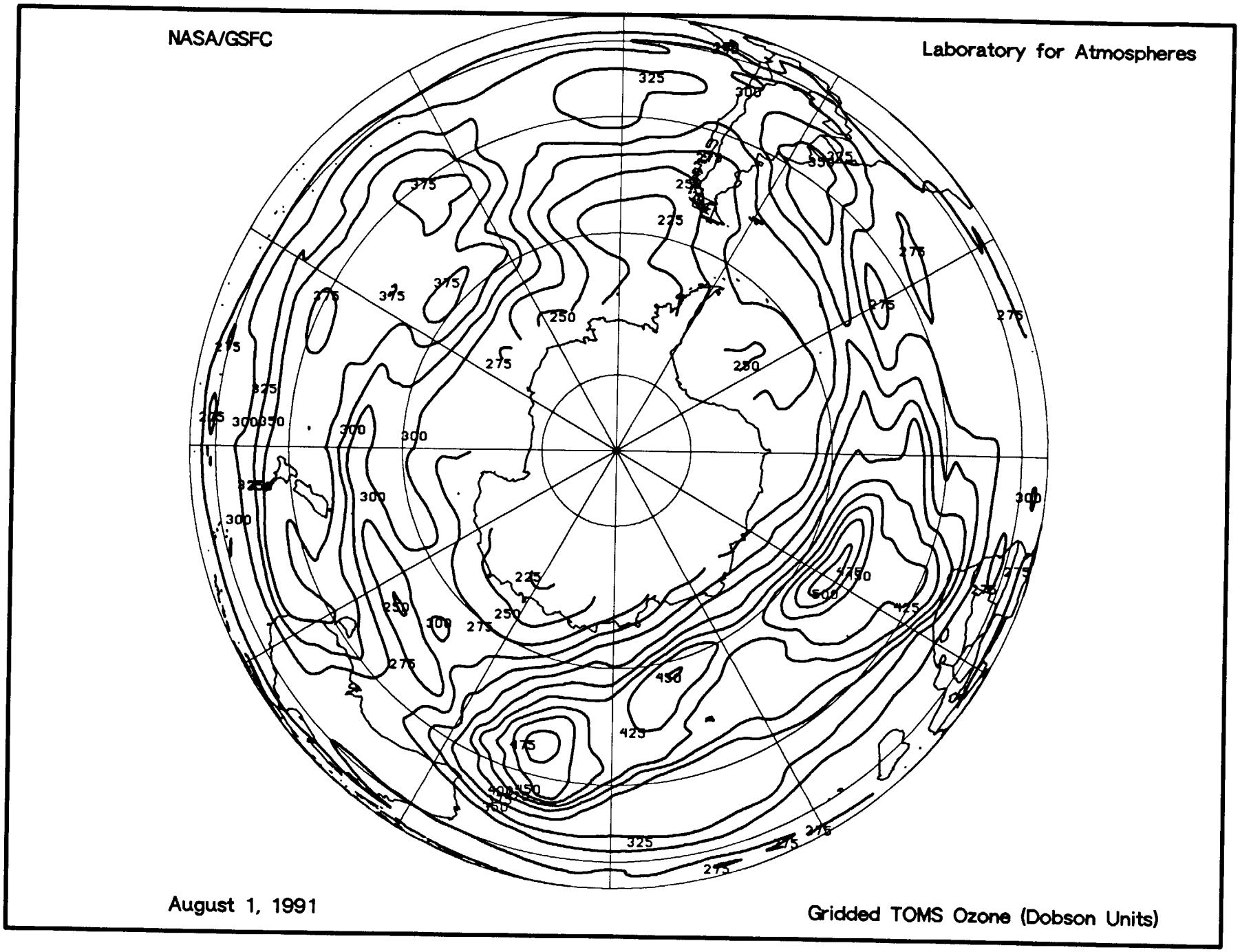
With total ozone values above 400 DU covering all of Wilkes Land and the Ross Sea, all that remains of the ozone hole is a very narrow strip of total ozone less that 275 DU extending from the southeast Pacific to the southwest Indian Ocean. A very small area with total ozone values below 225 DU exists over the southeast Pacific Ocean. This period marks the breakup of the south polar vortex.

NOVEMBER 21, 1991

All that is left of the 1991 Antarctic ozone hole is a small area with total ozone between 225 and 250 DU over the southeast Pacific Ocean. Total ozone values throughout Antarctica are above 275 DU.

2.2 Southern Hemisphere Polar Charts

A set of daily TOMS total ozone estimates for the Southern Hemisphere, over the period August 1 through November 30, 1991 is presented here. The daily data are resolved on a uniform 2° latitude by 5° longitude grid for each day, and displayed using a south-polar orthographic projection. The advantage of this projection is that emphasis is placed over precisely those high-latitude regions of interest in the Antarctic region.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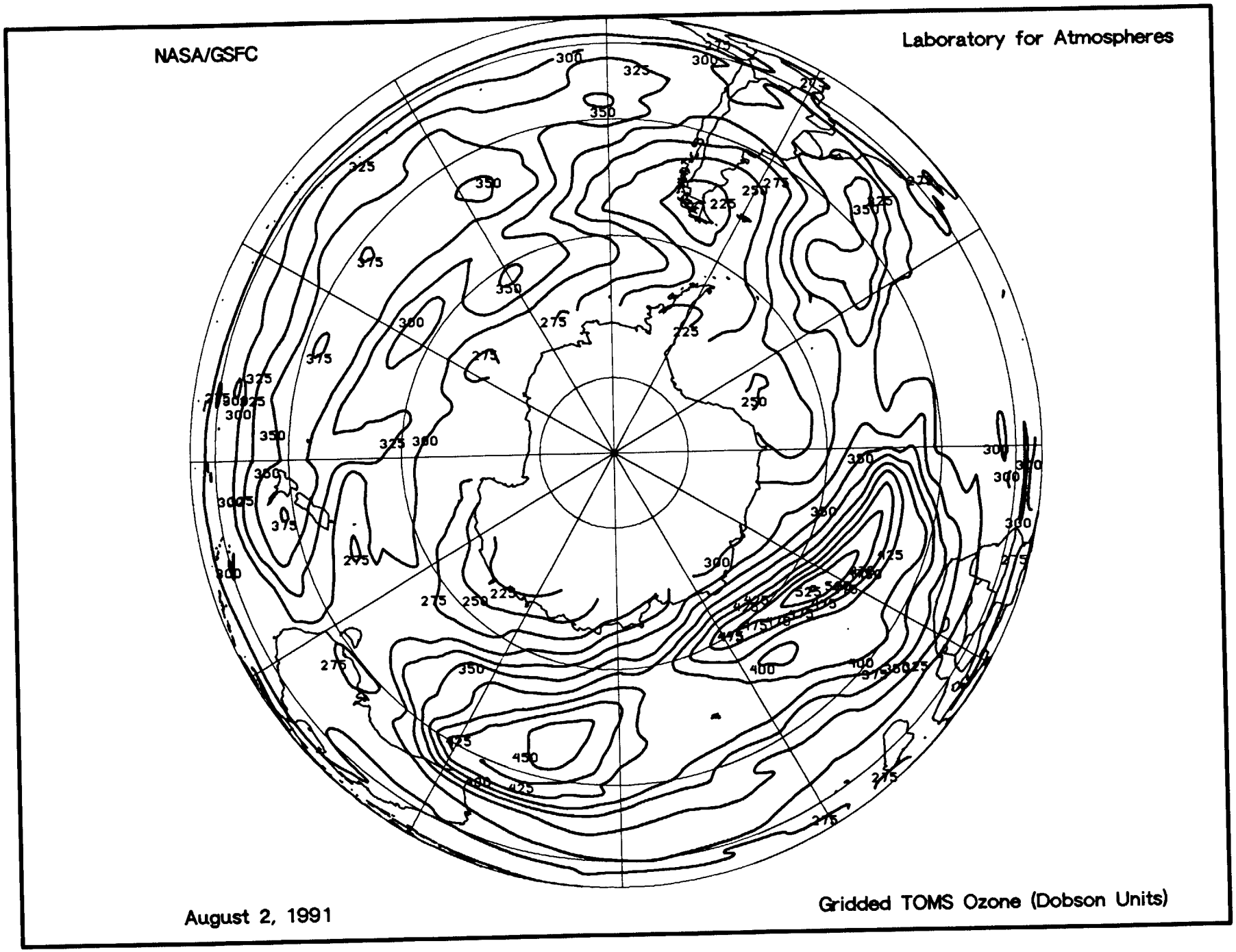
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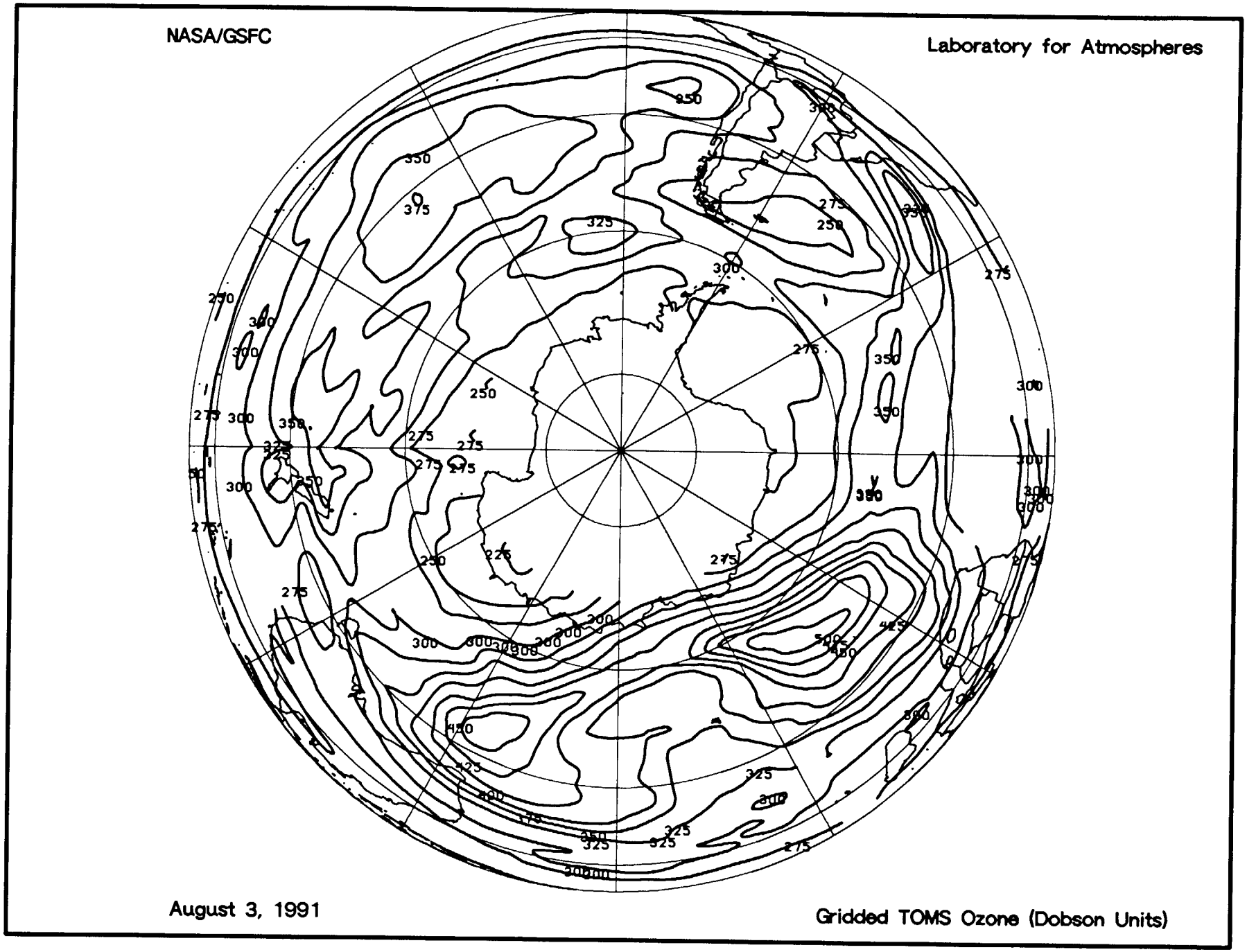
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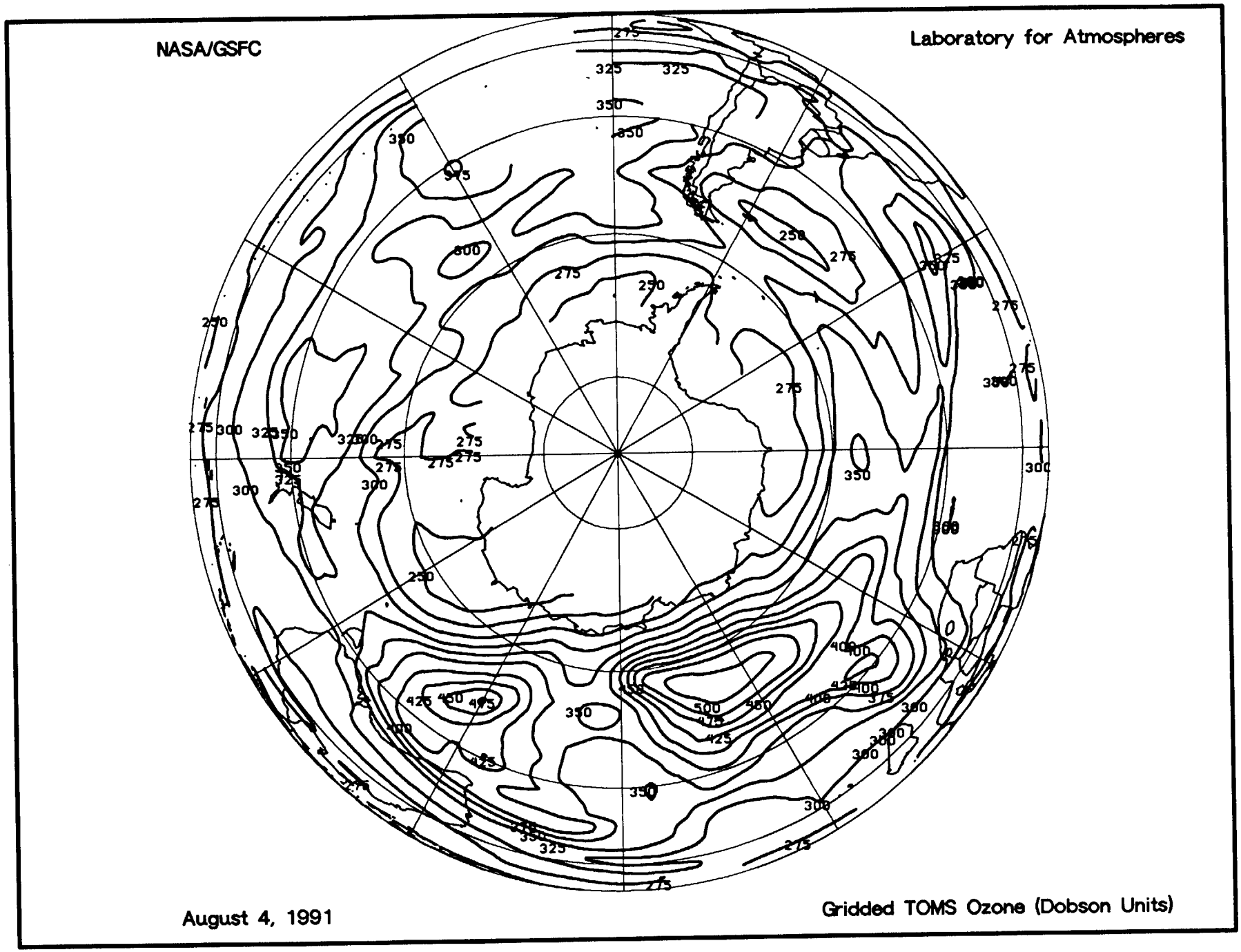
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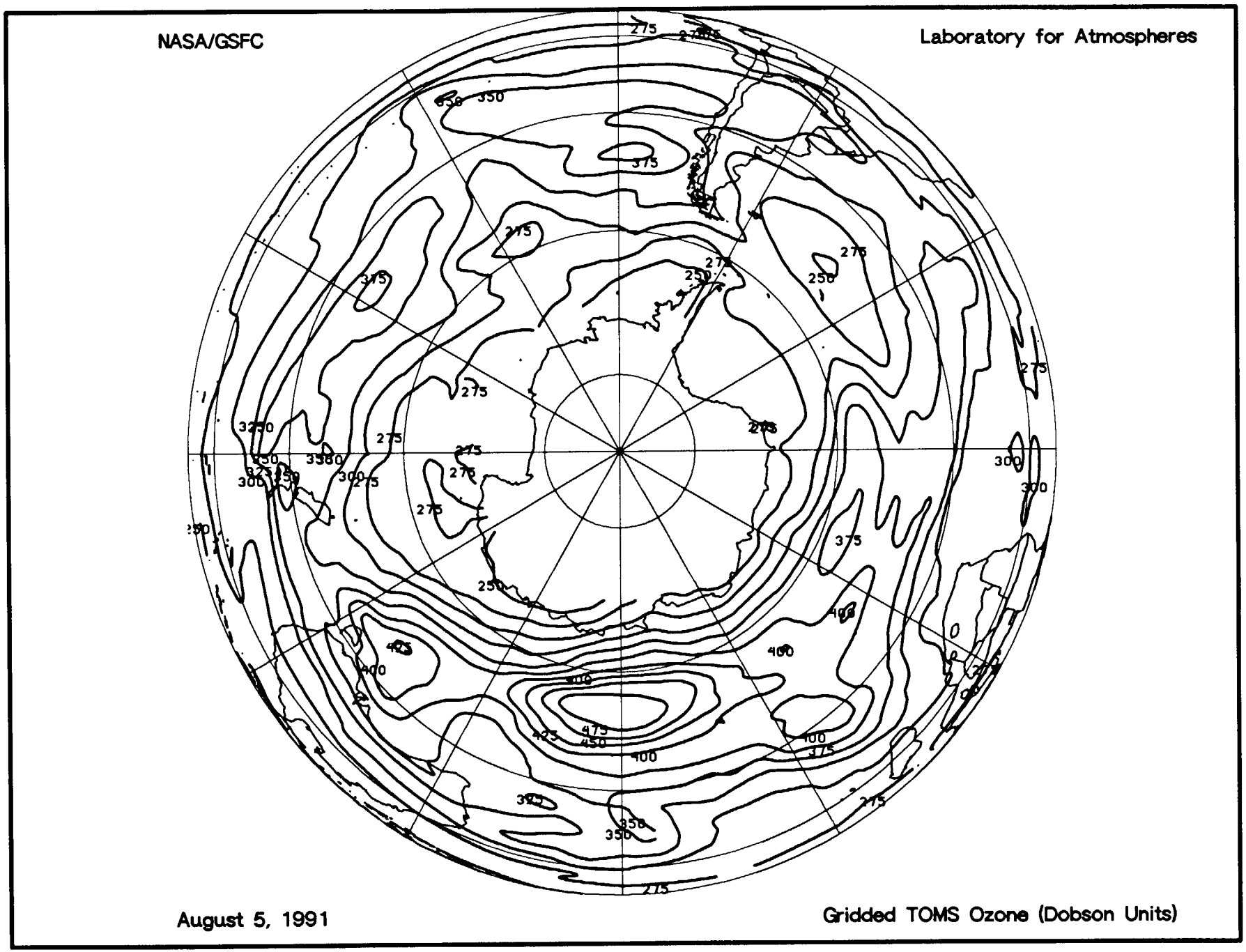
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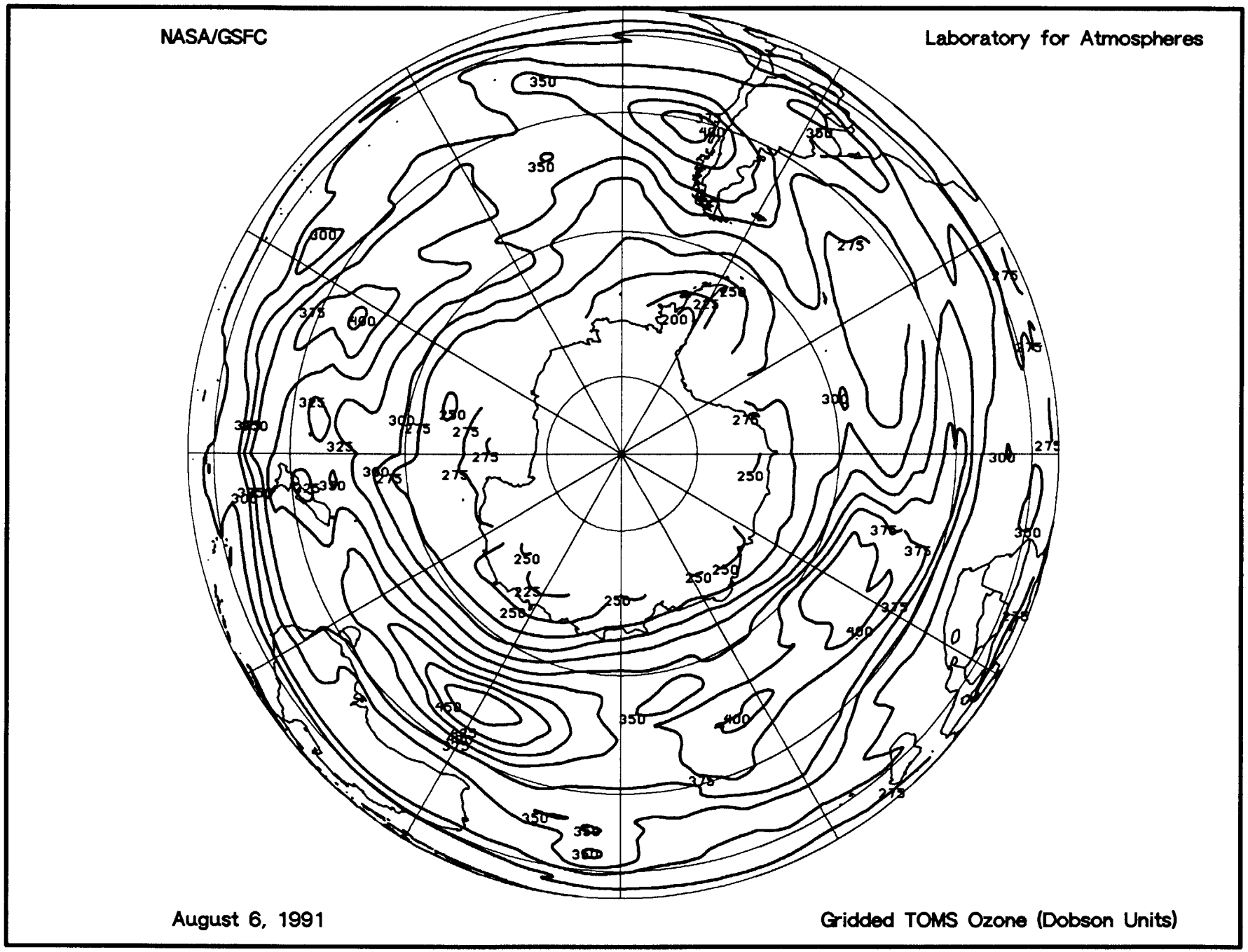
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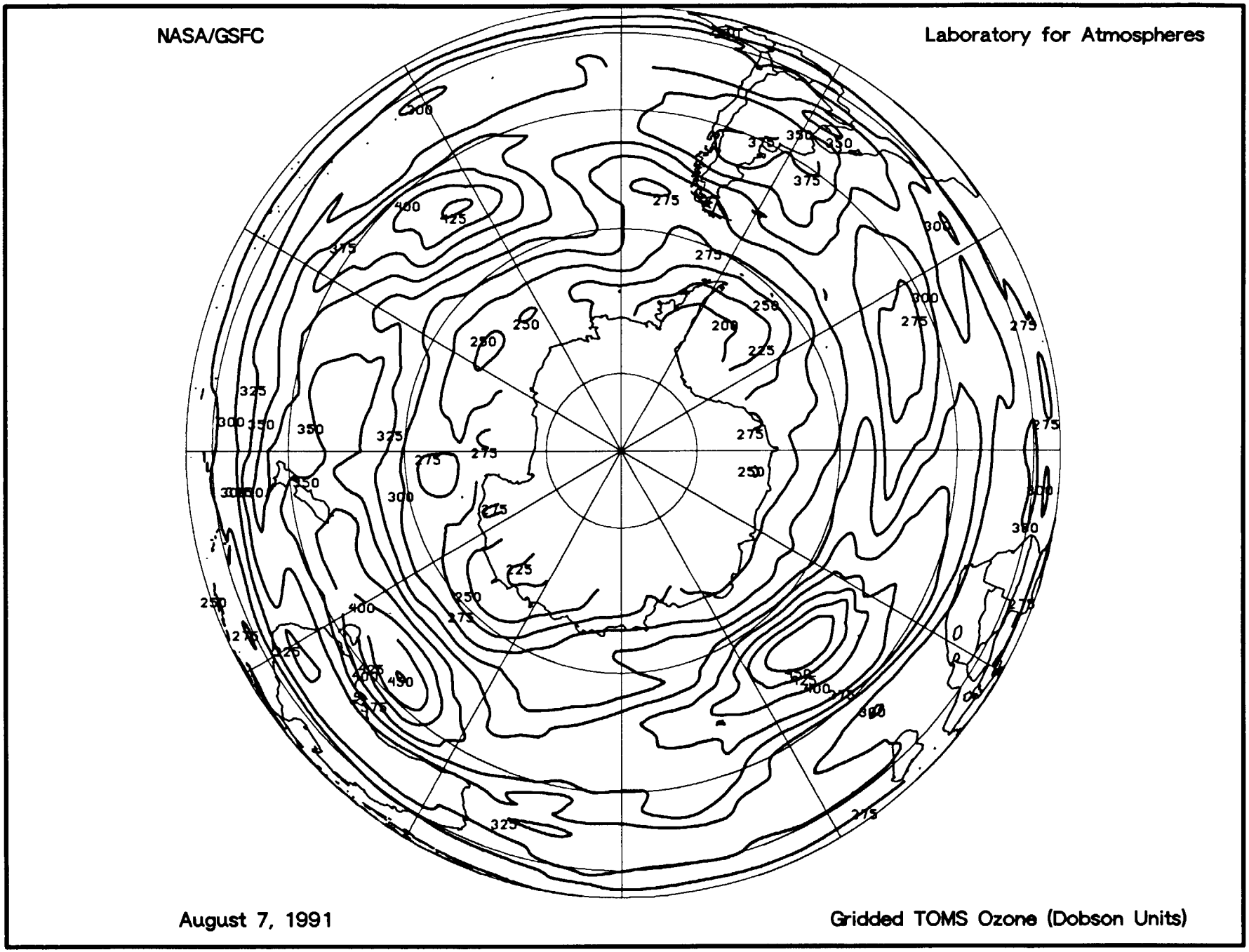
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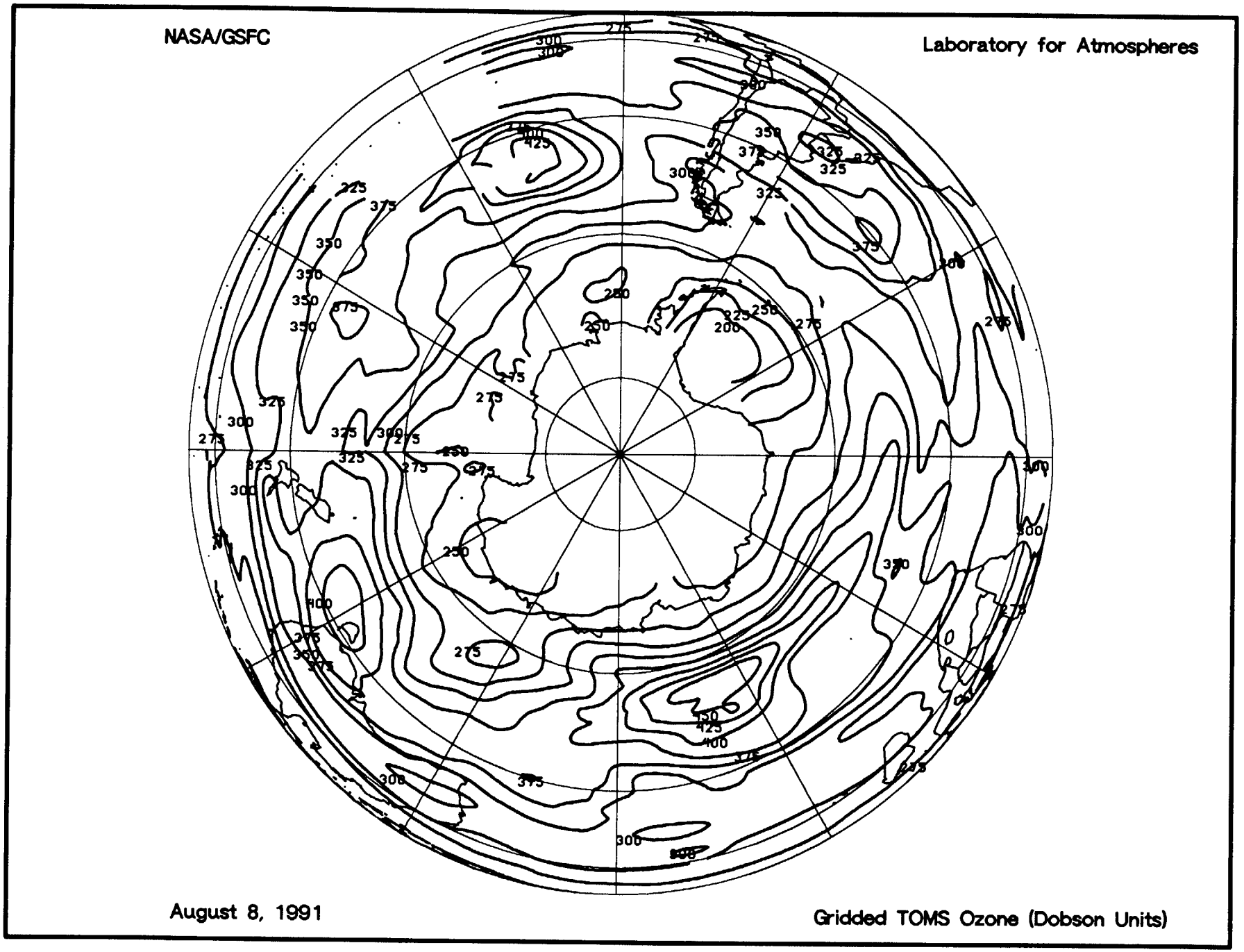
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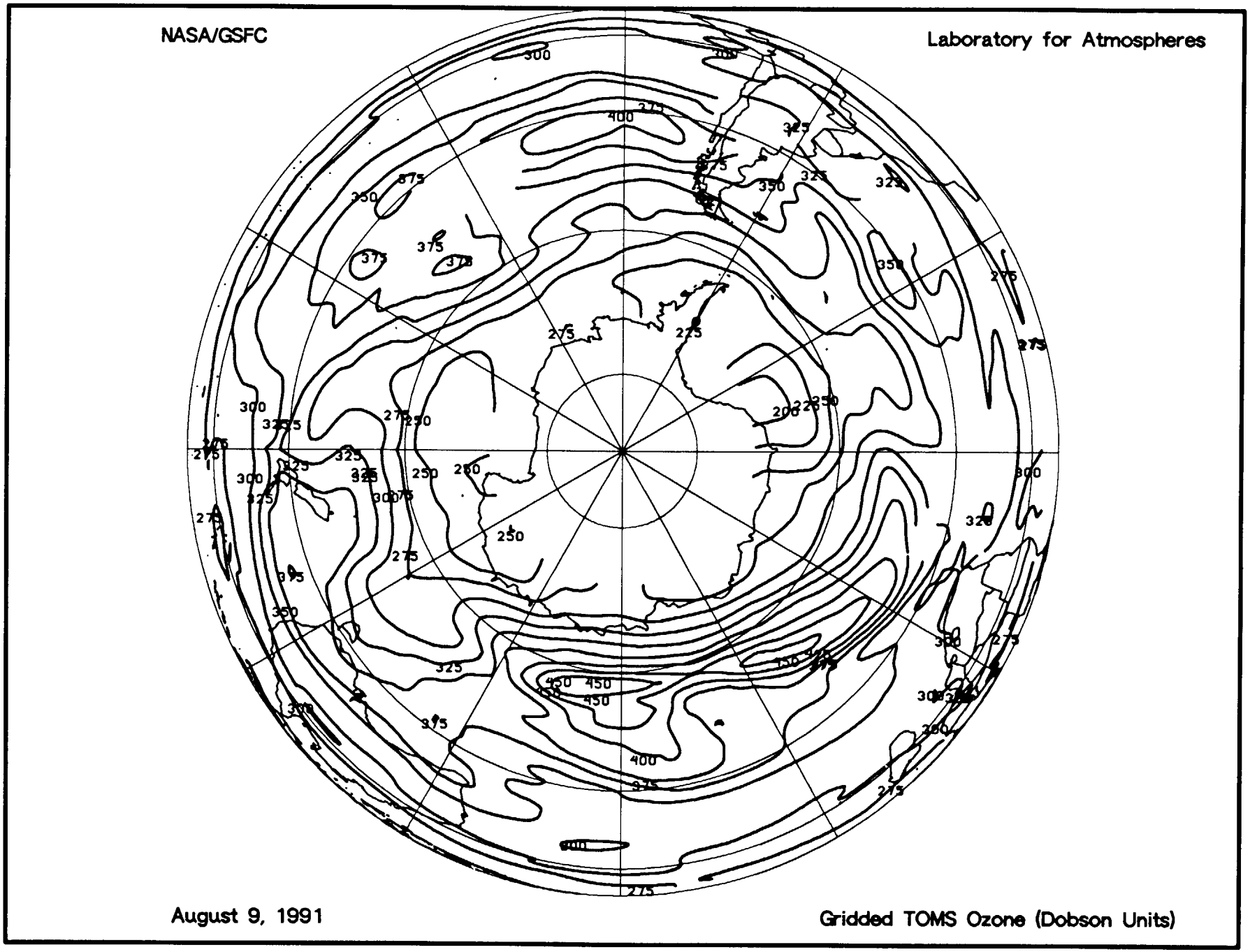
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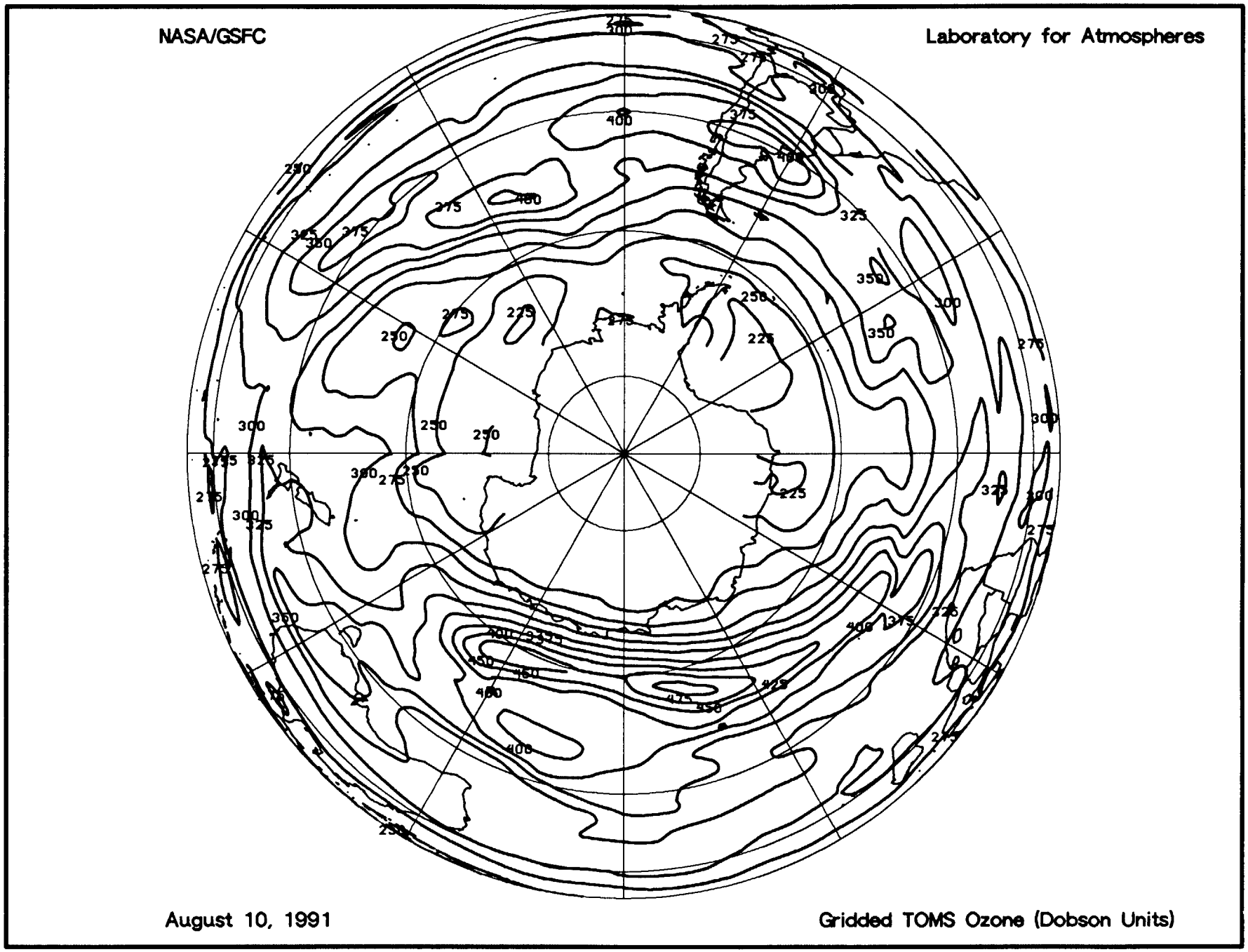
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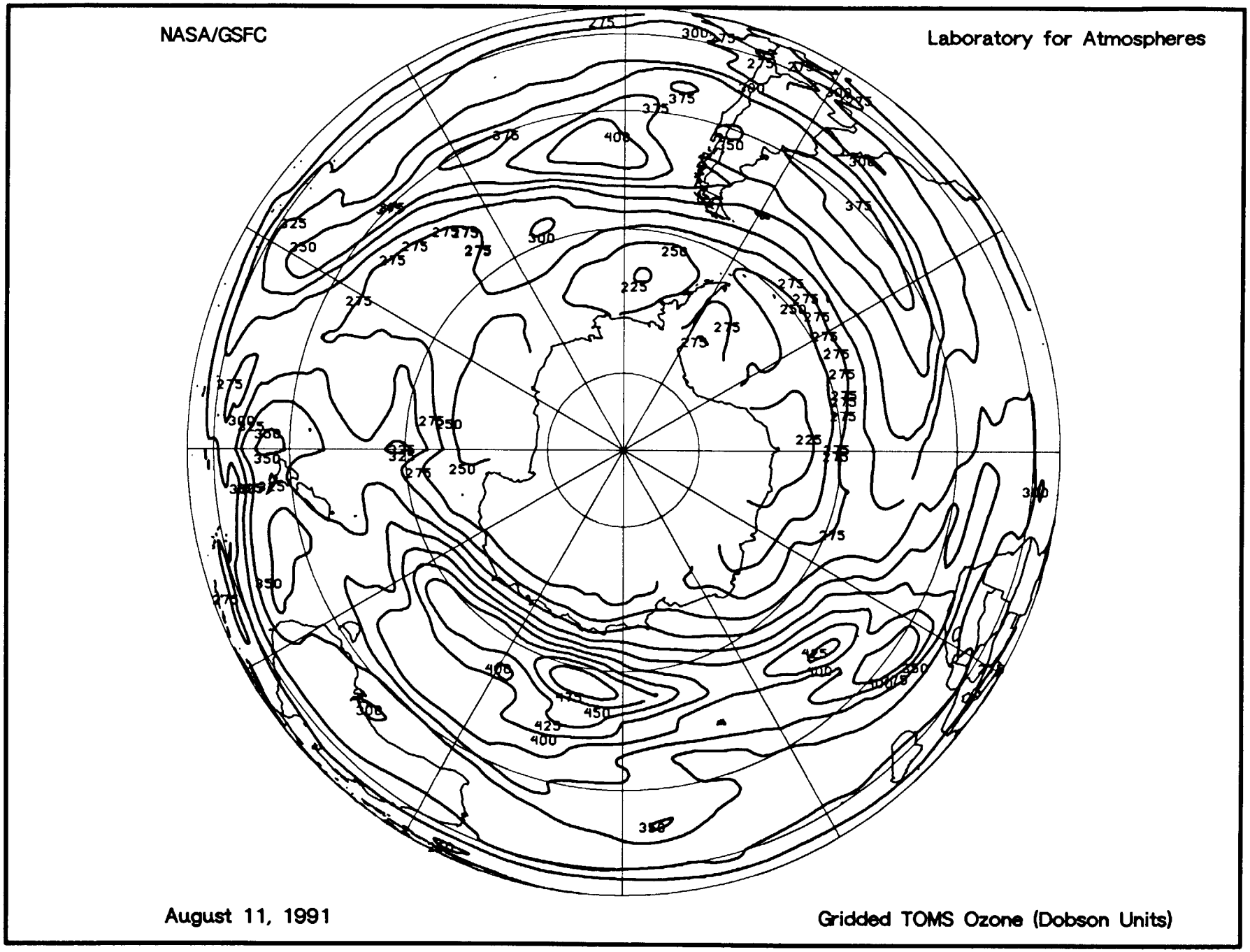
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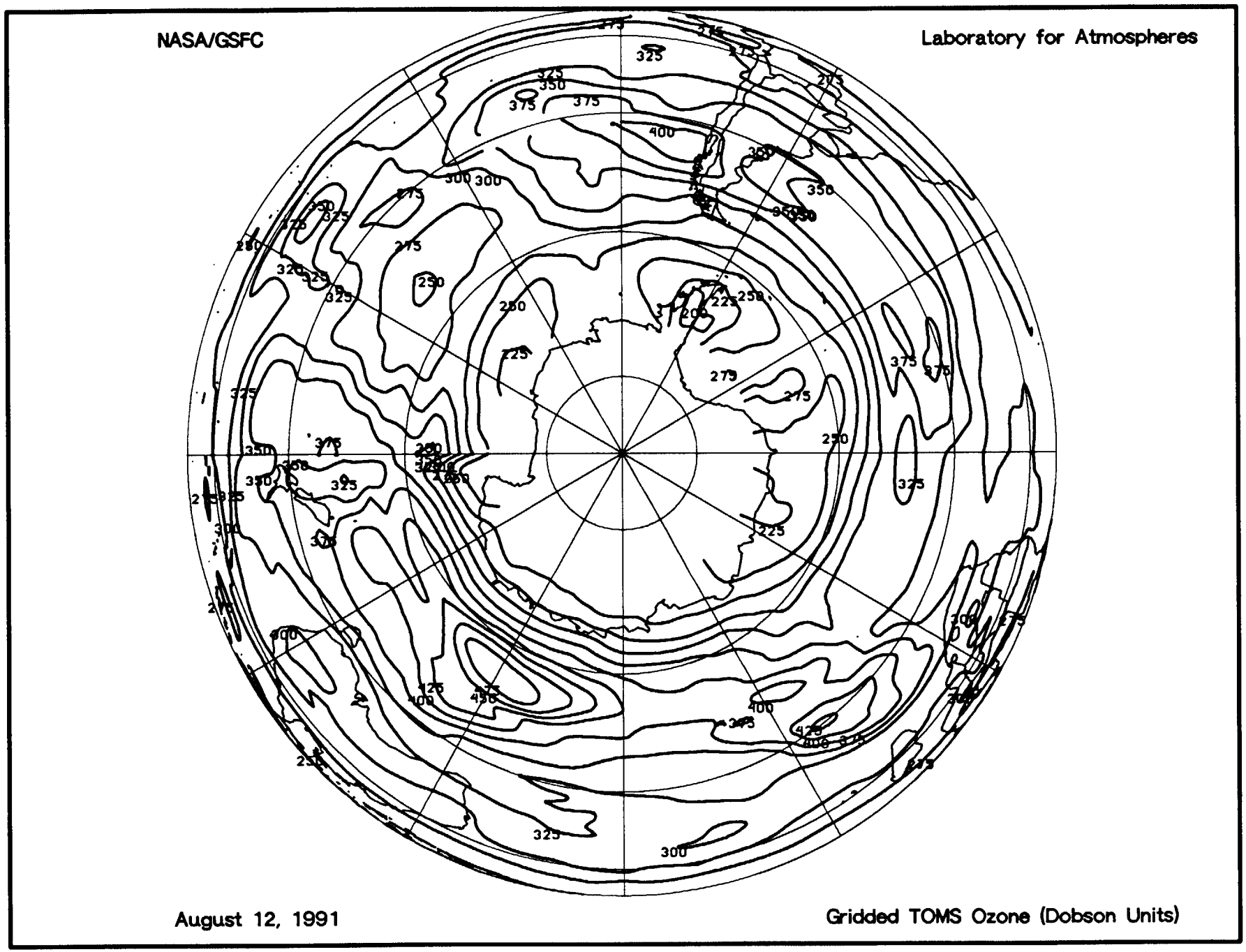
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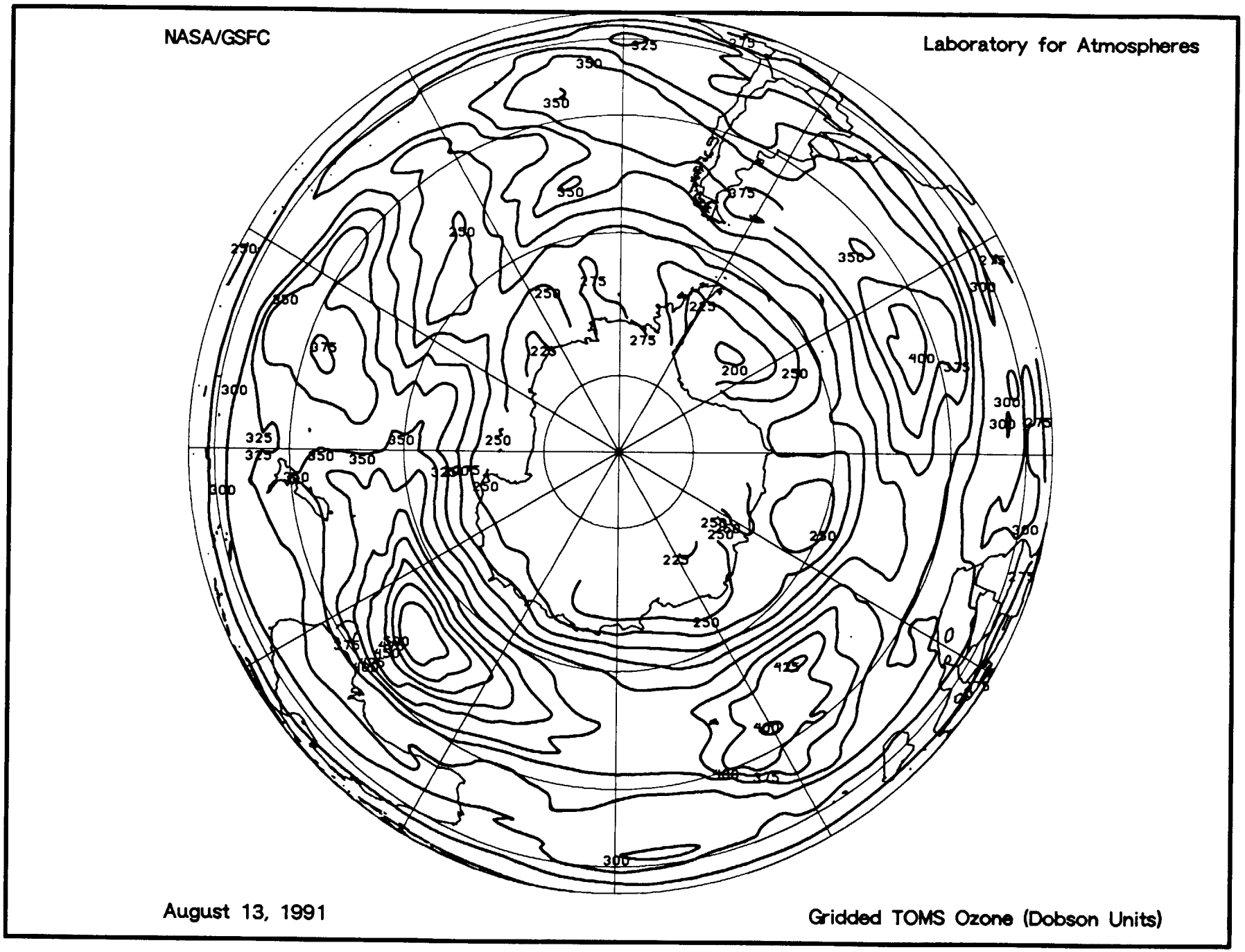
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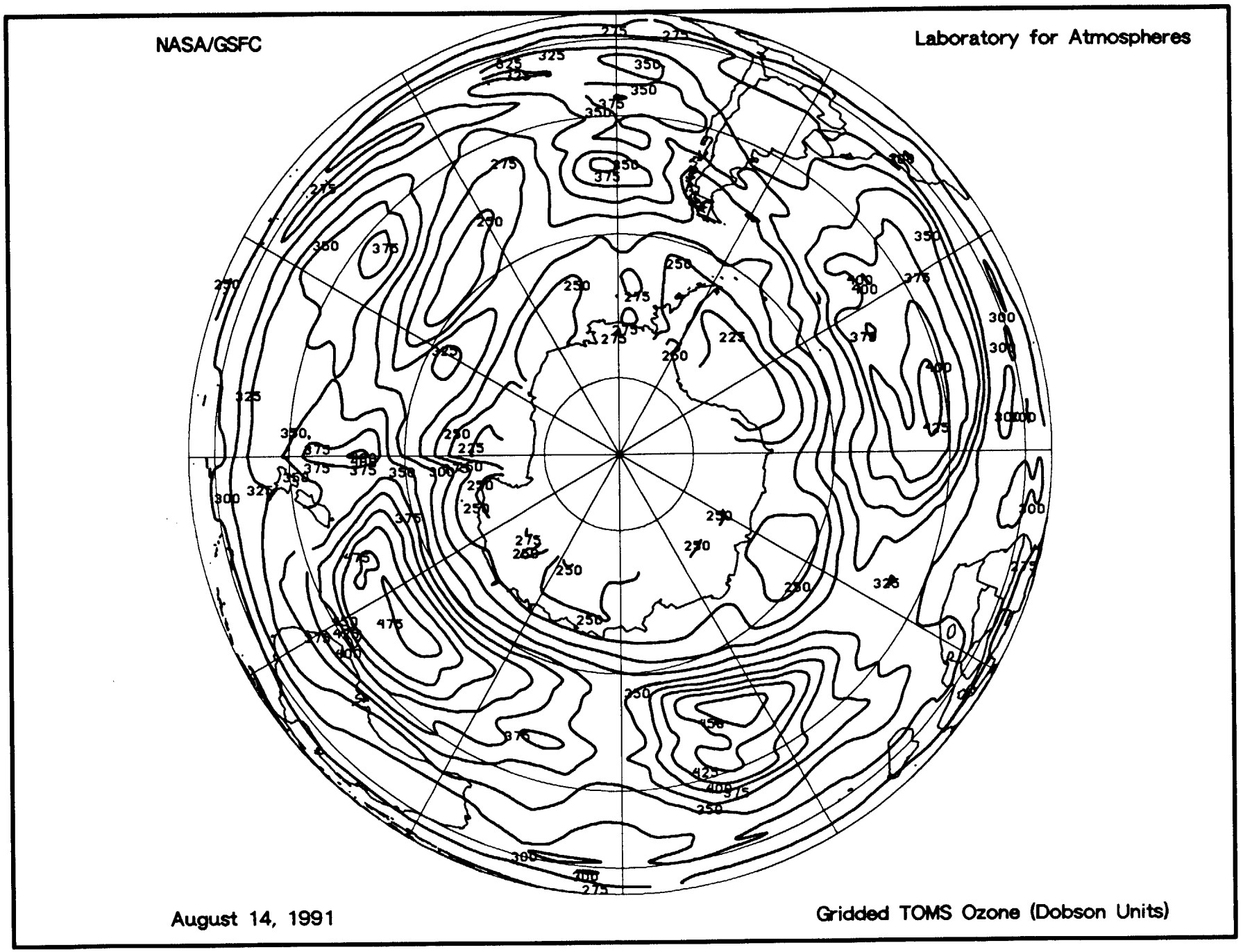
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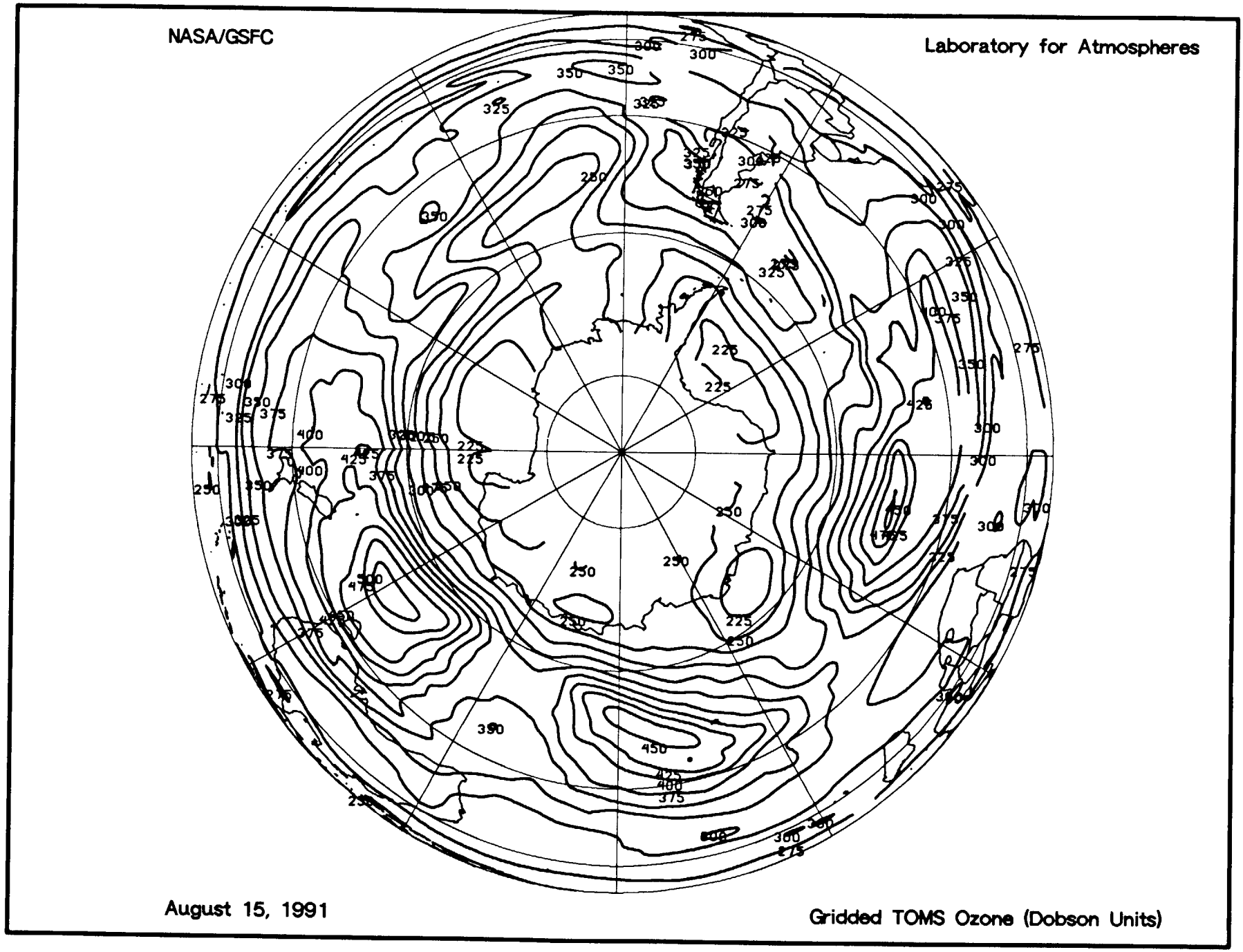
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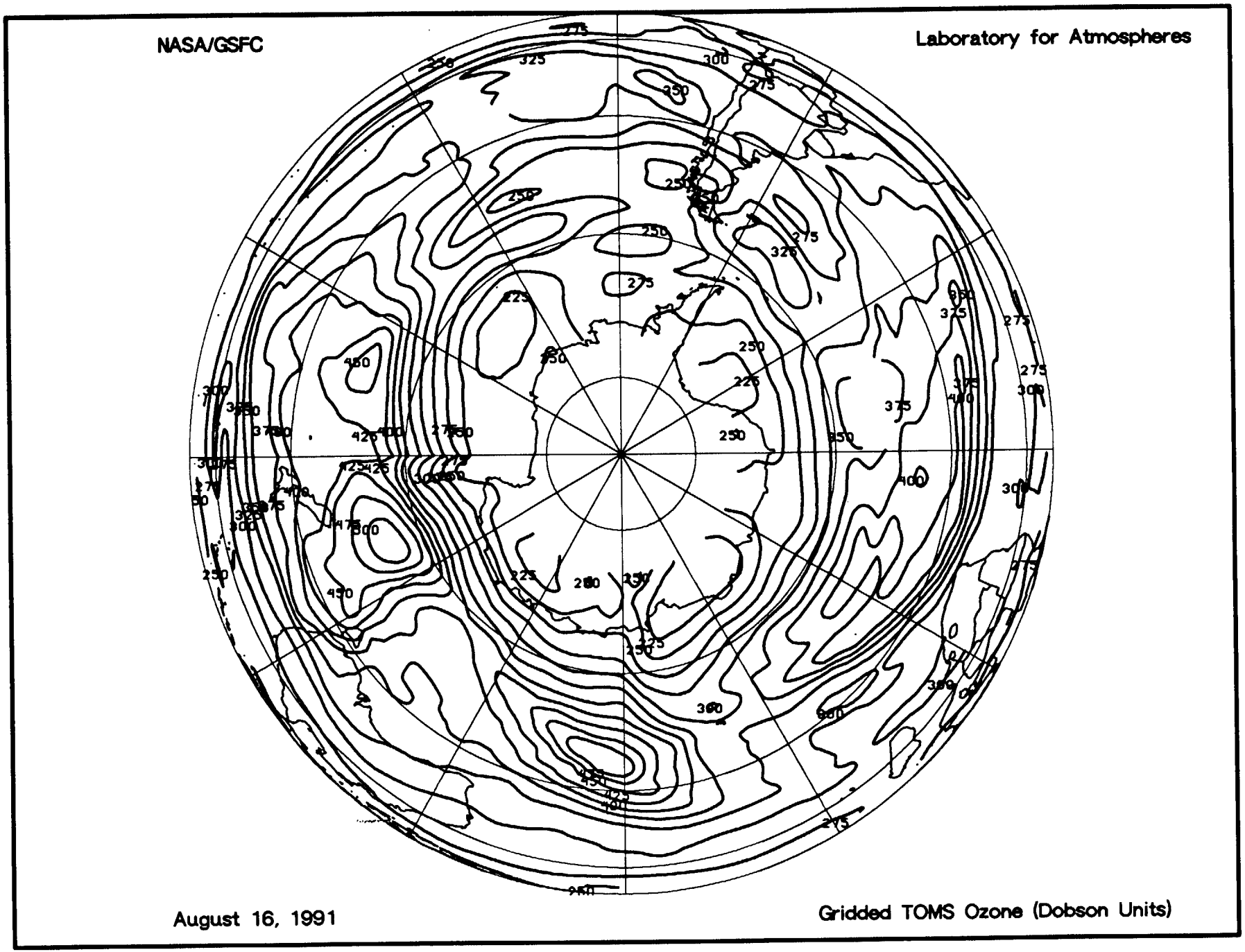
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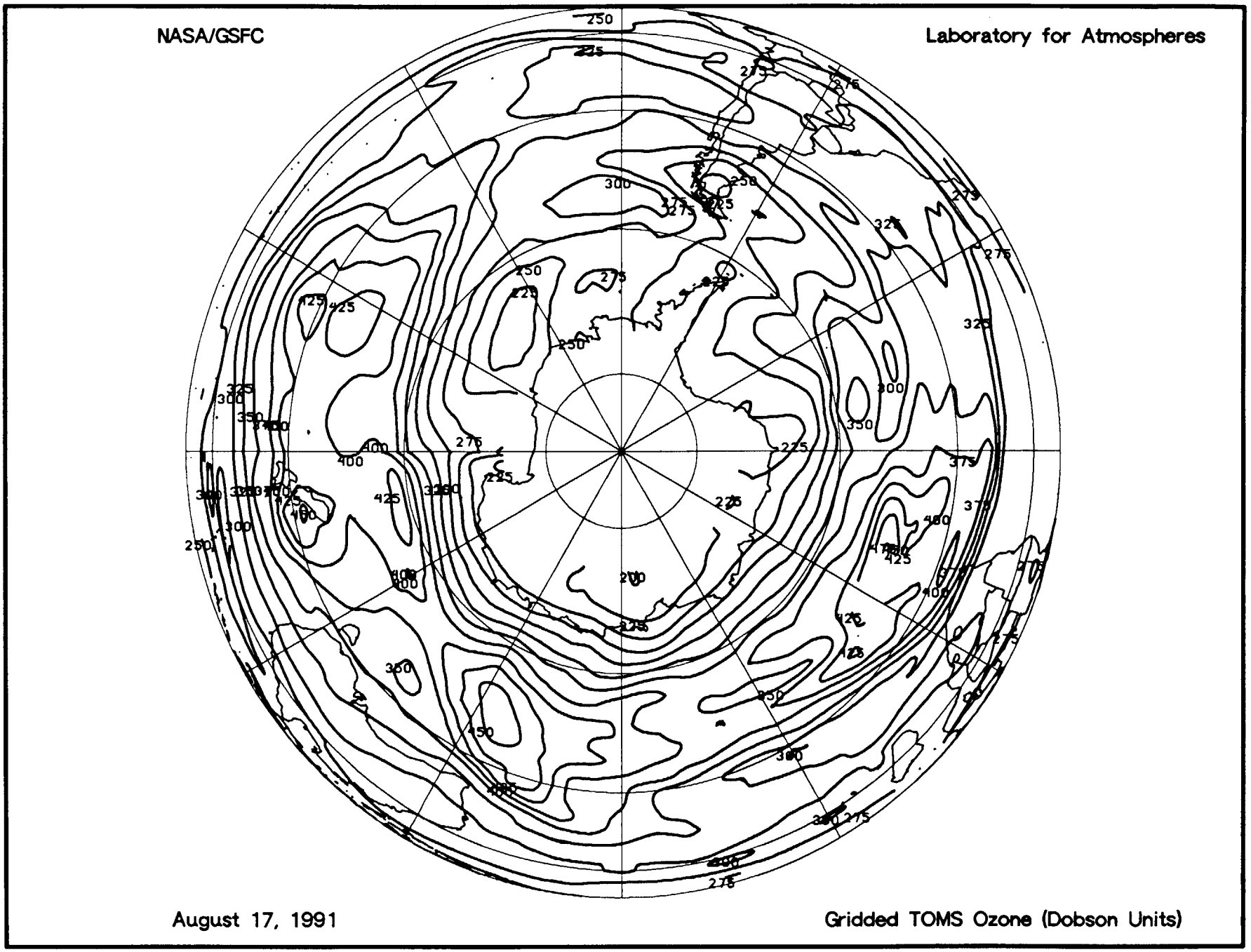
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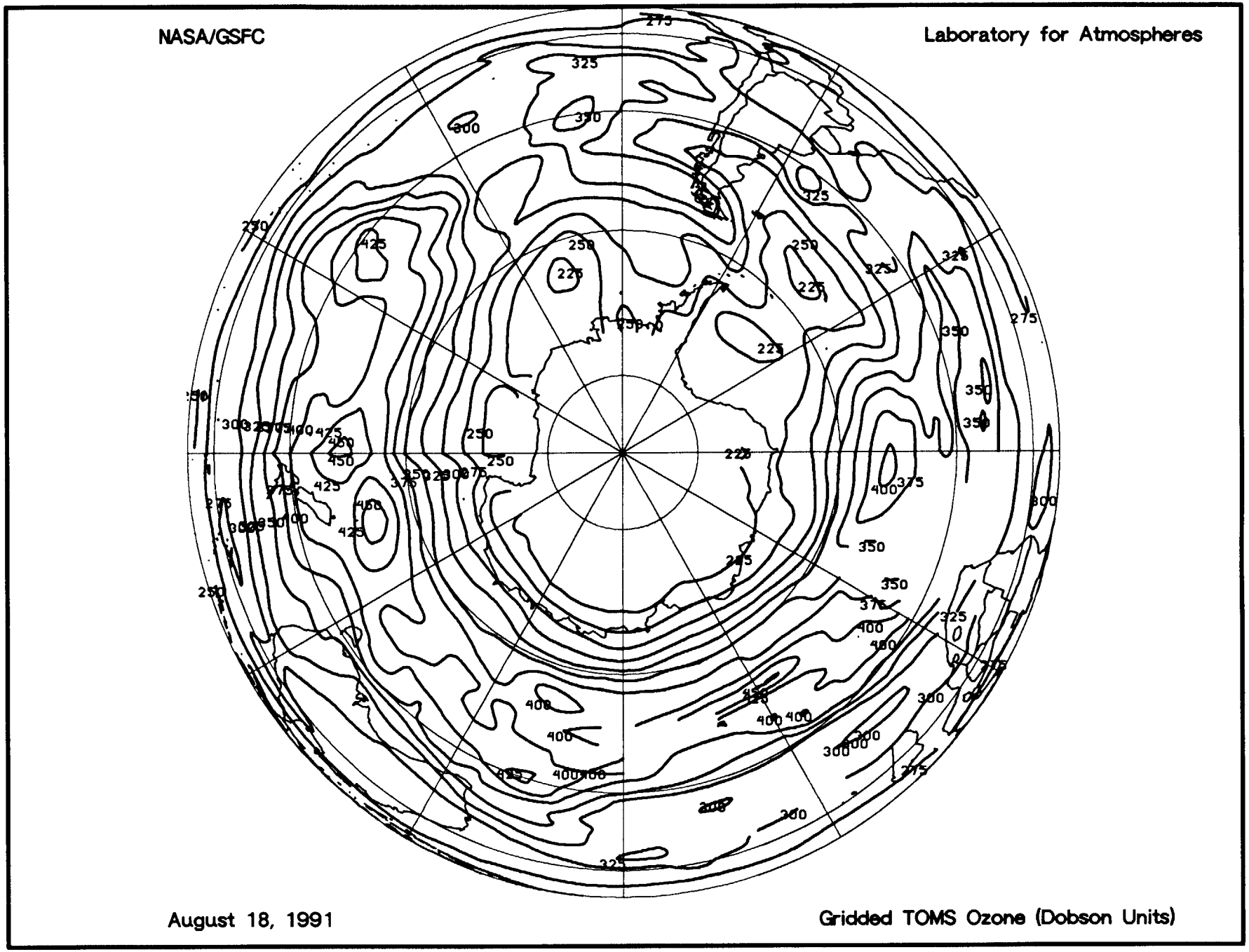
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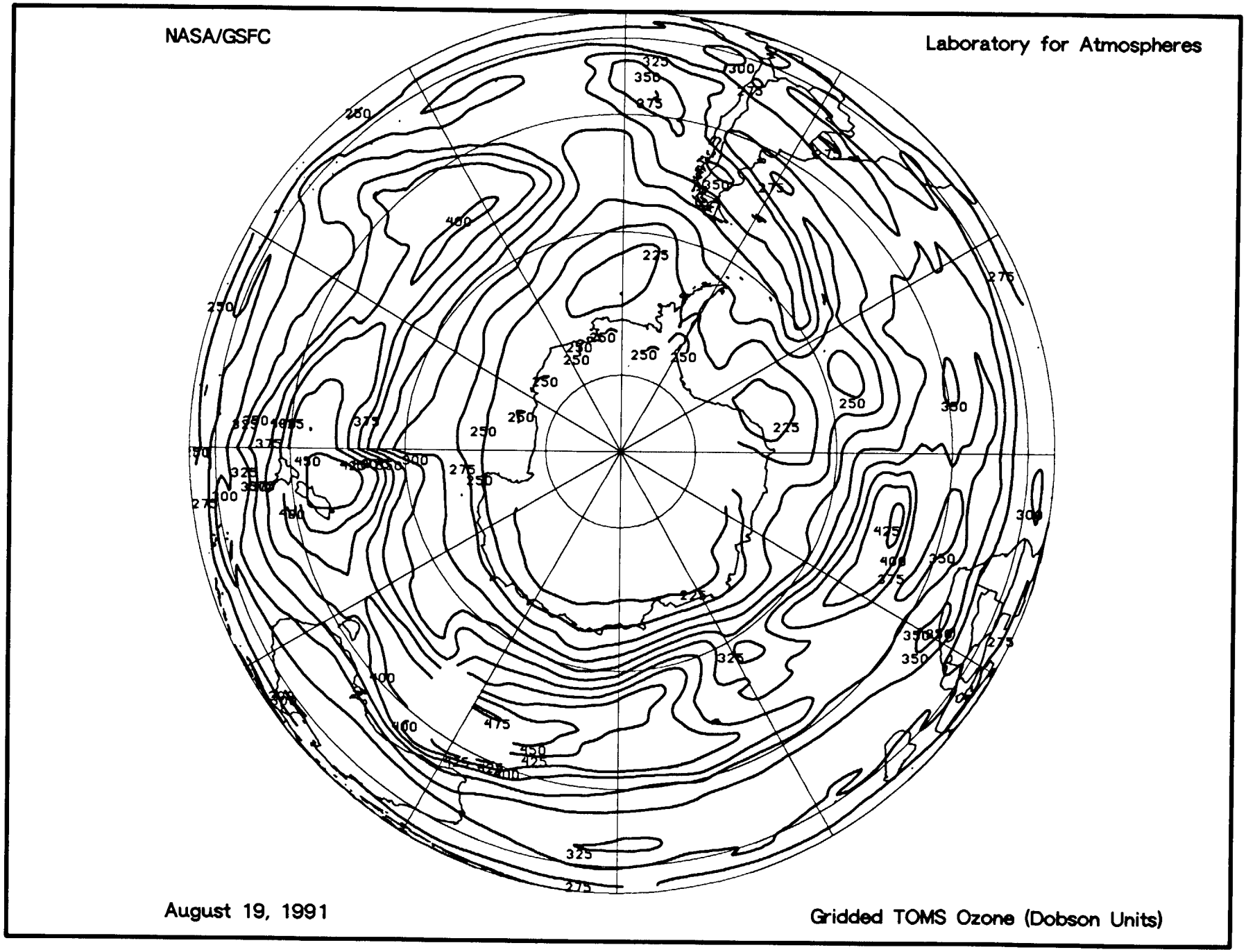
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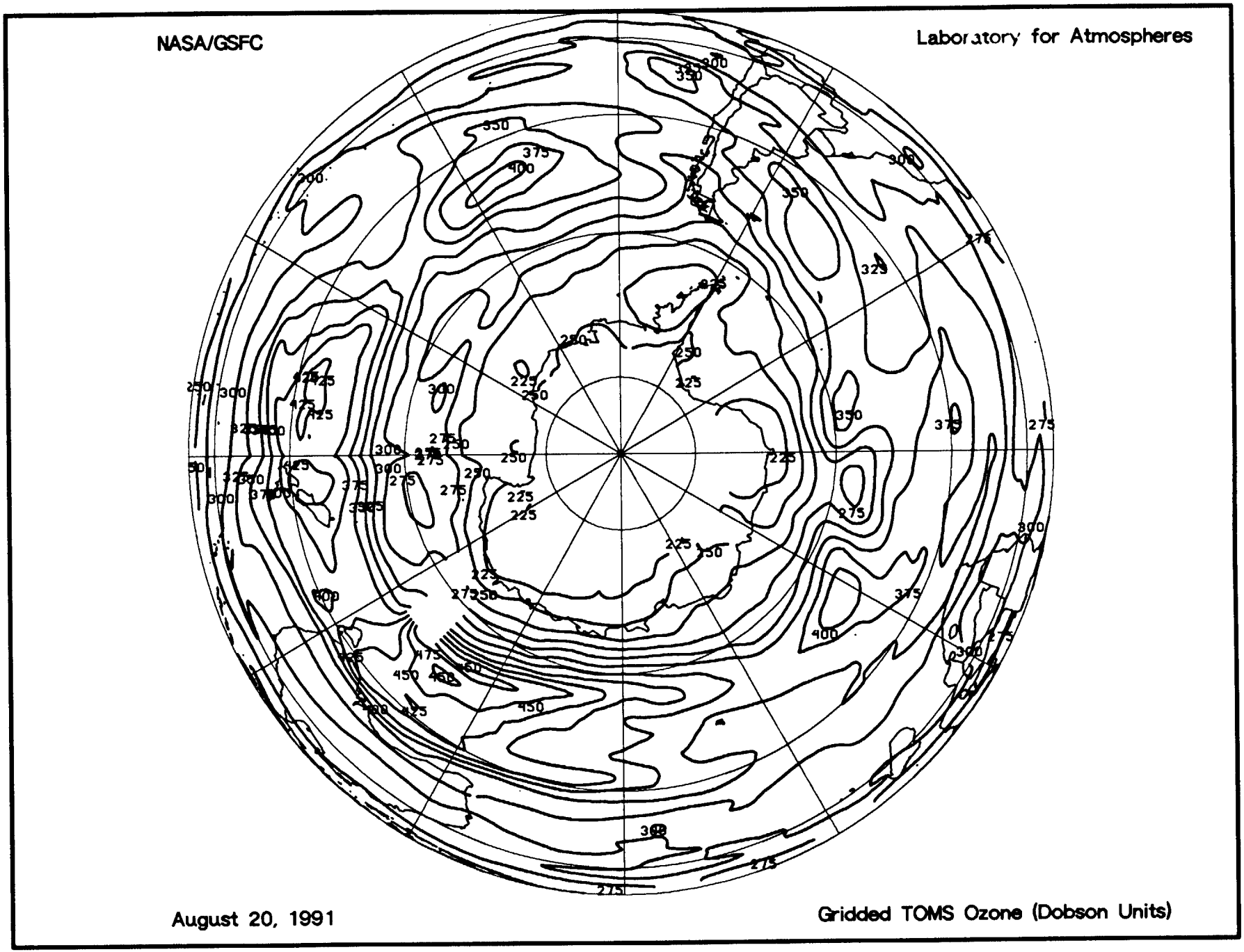
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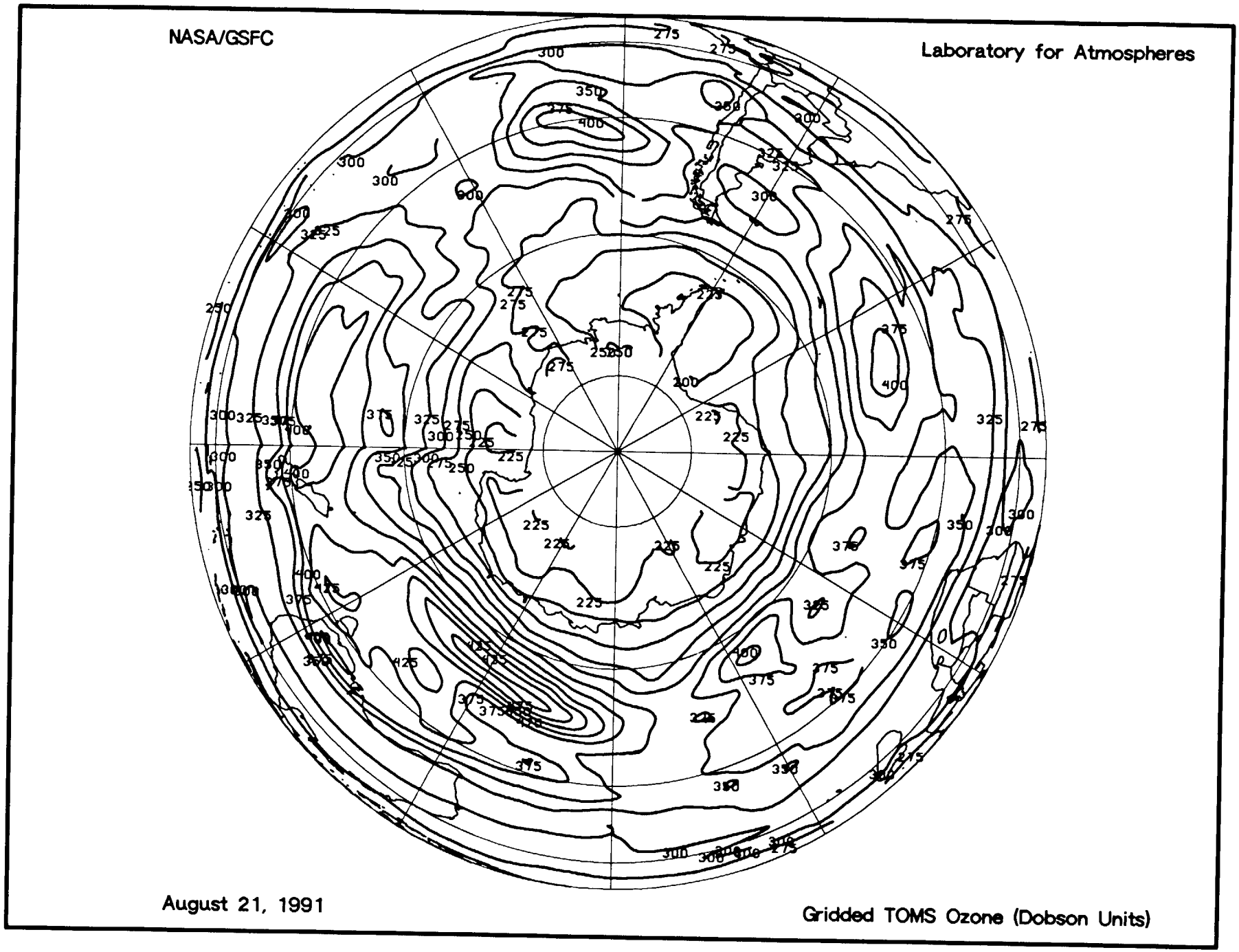
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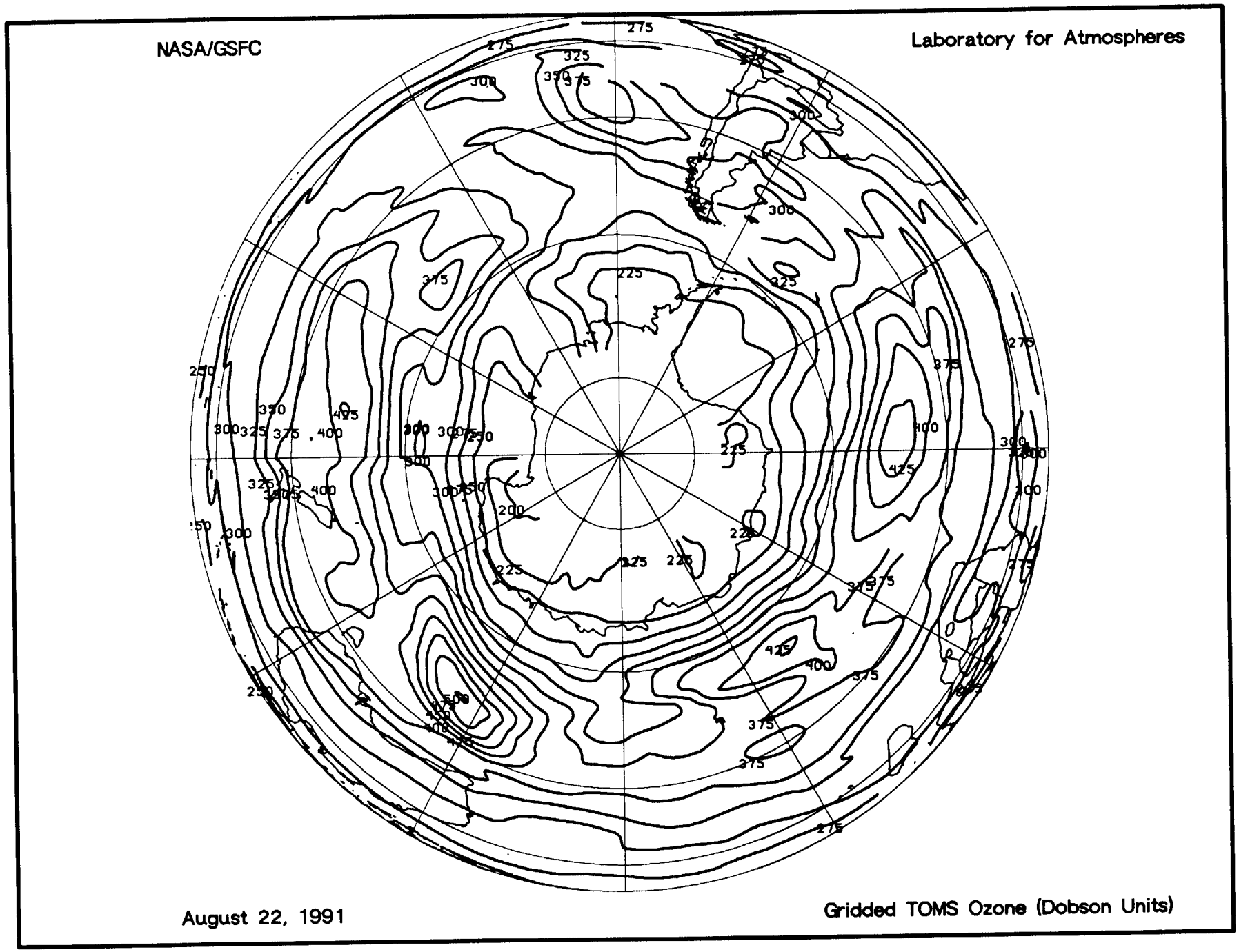
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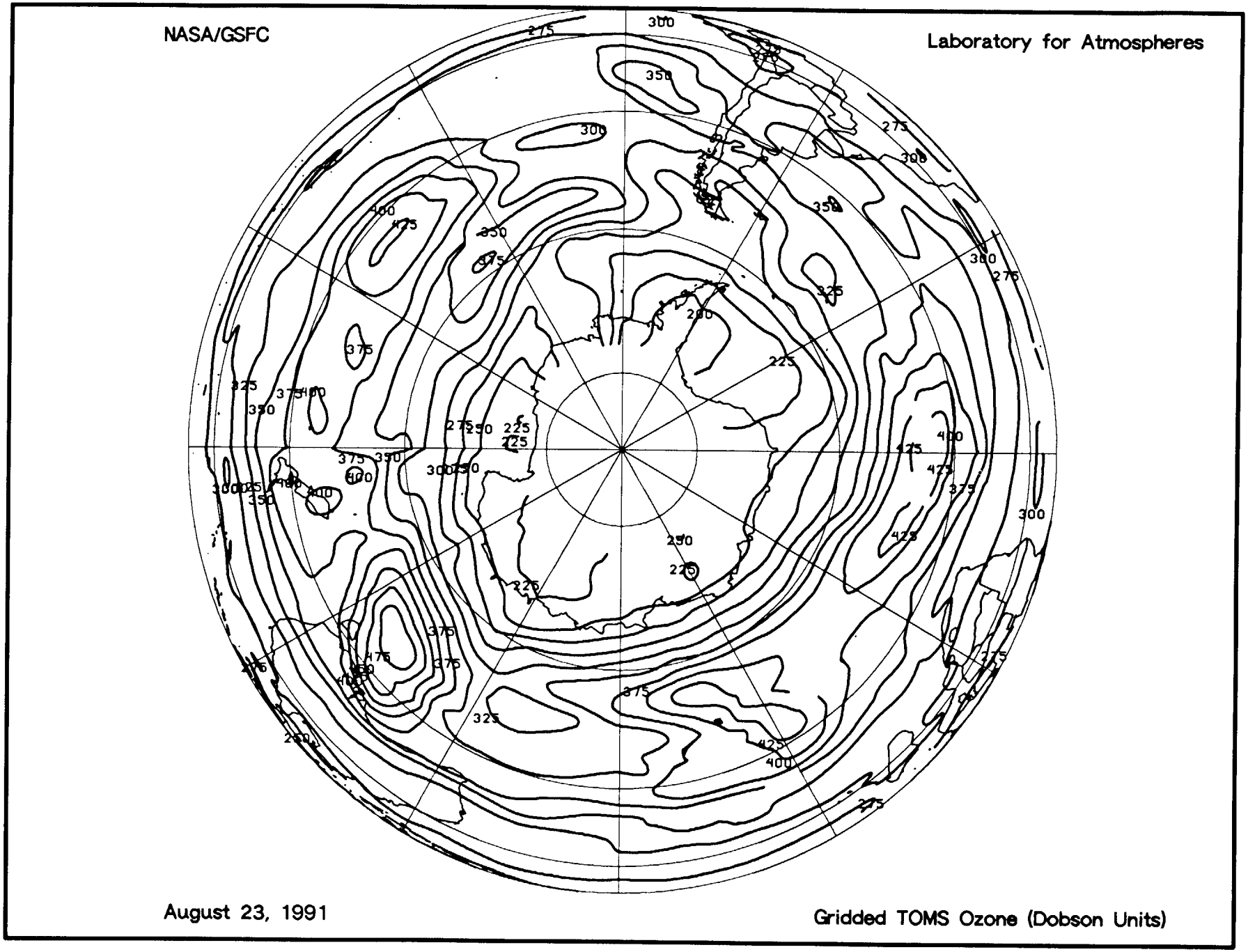
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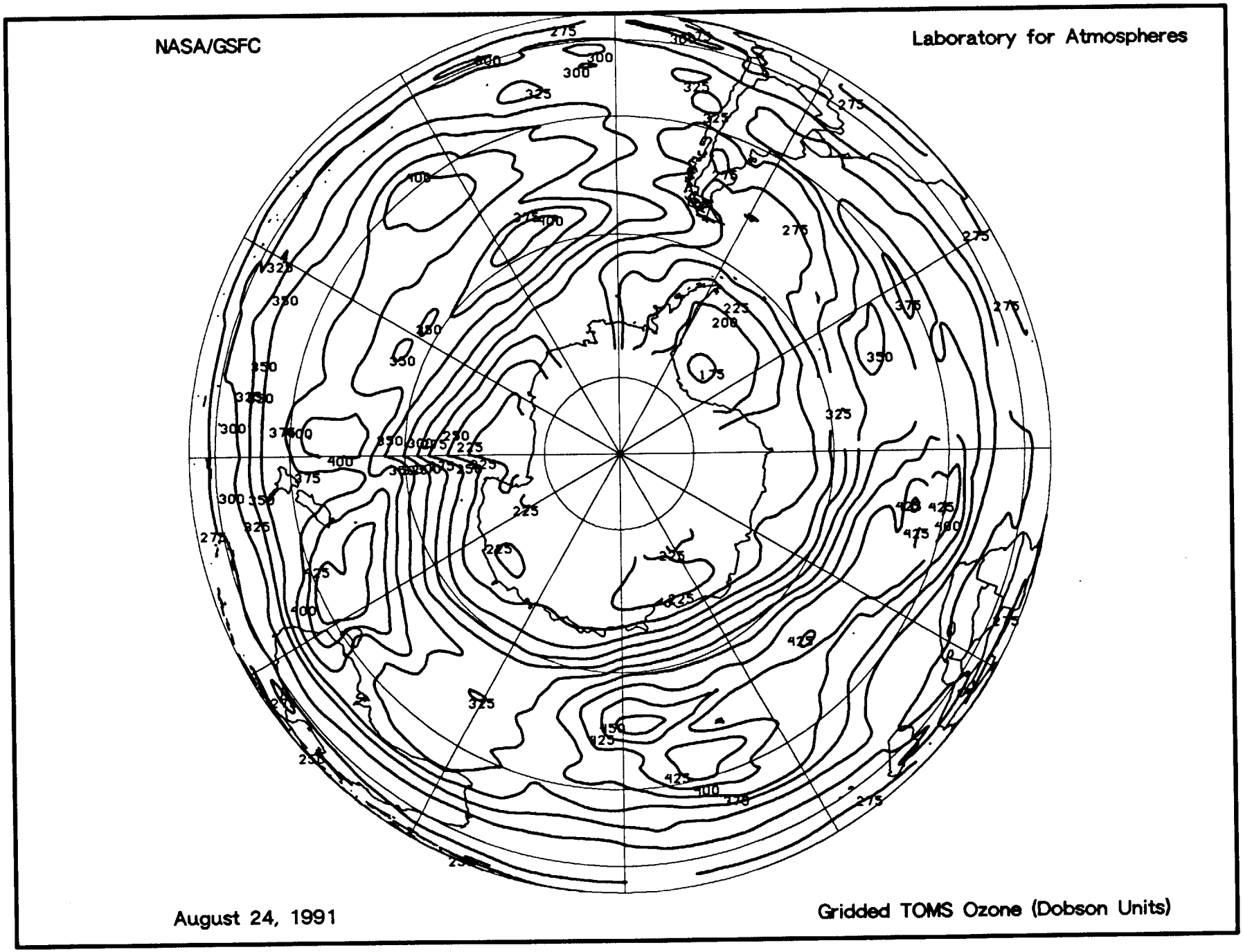
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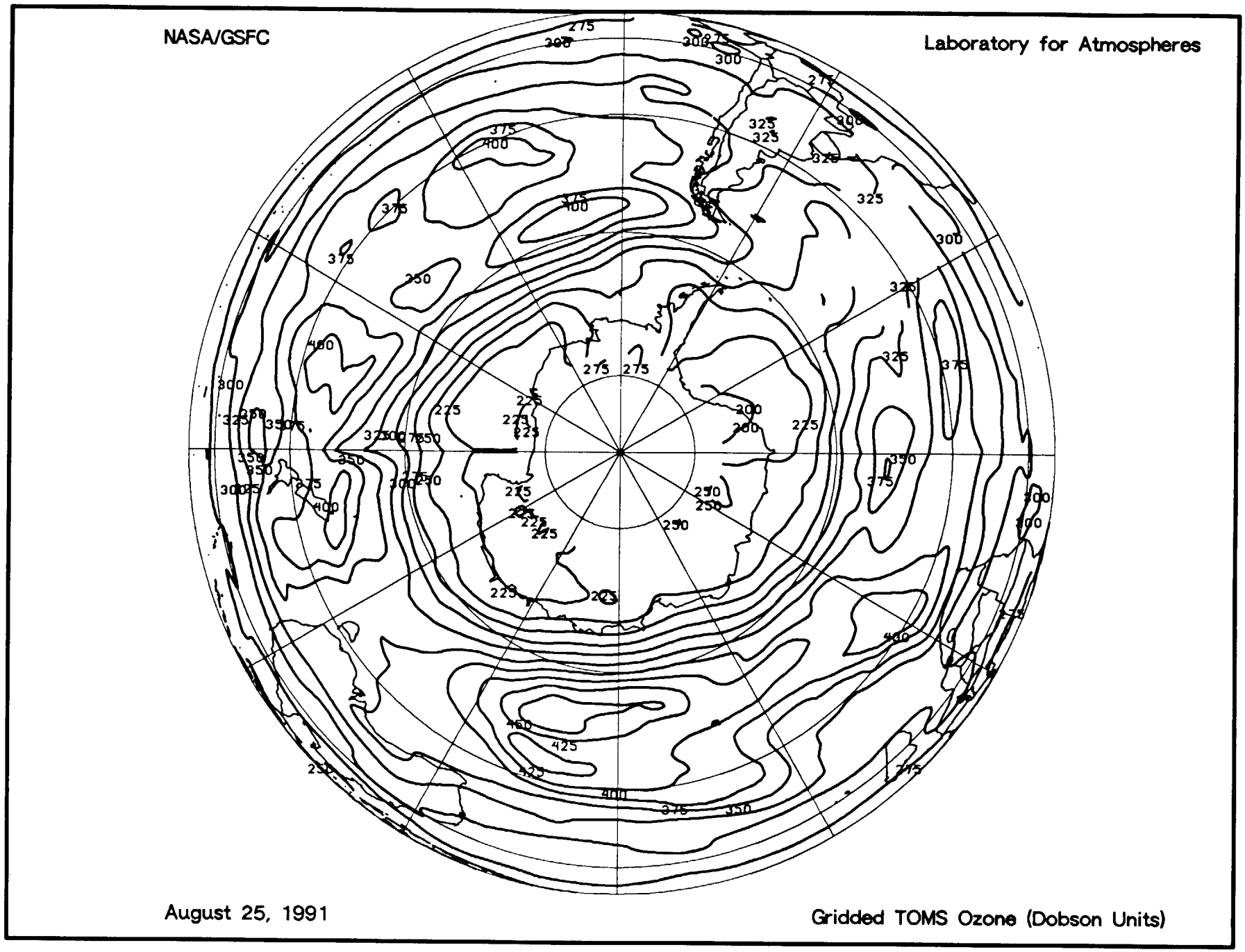
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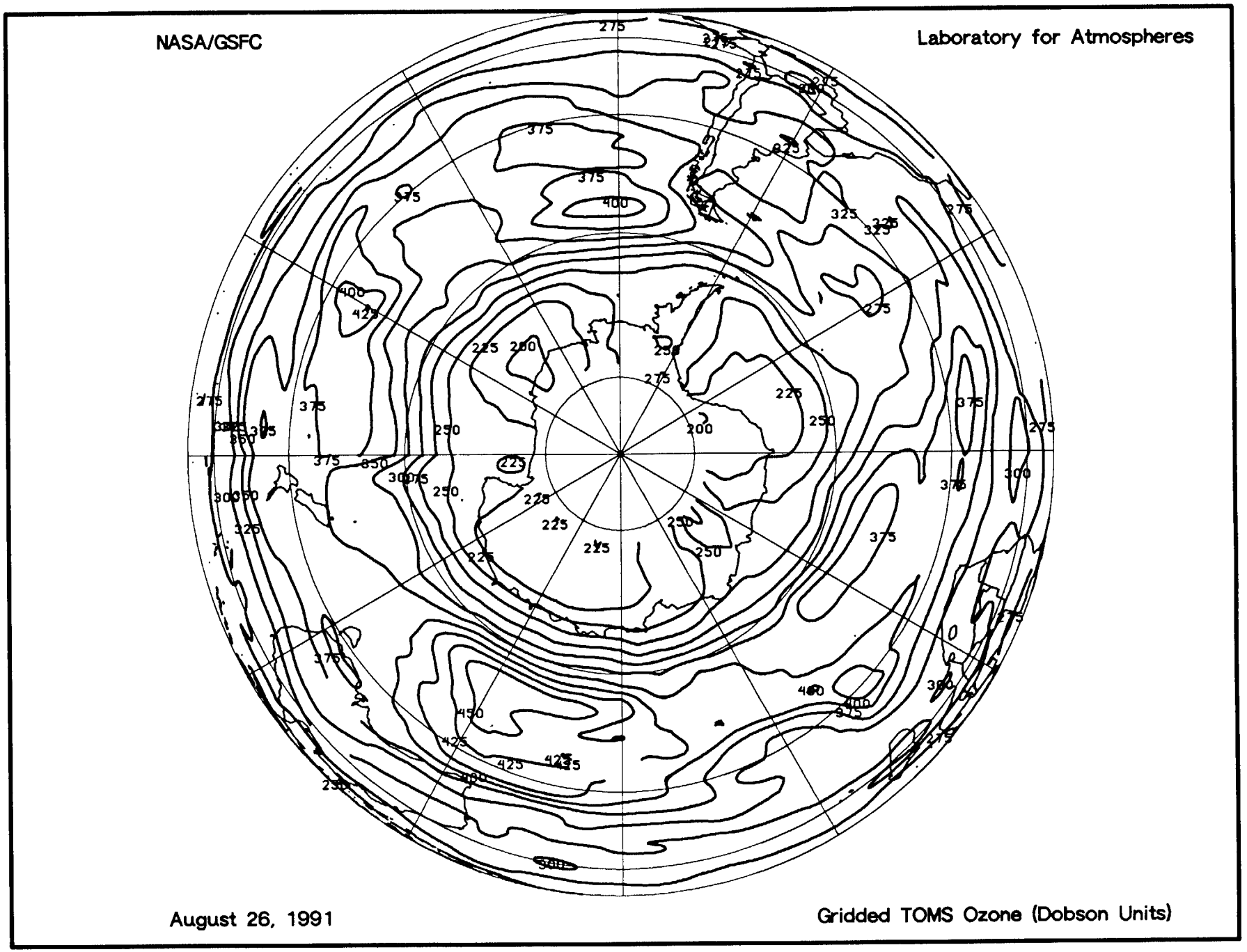
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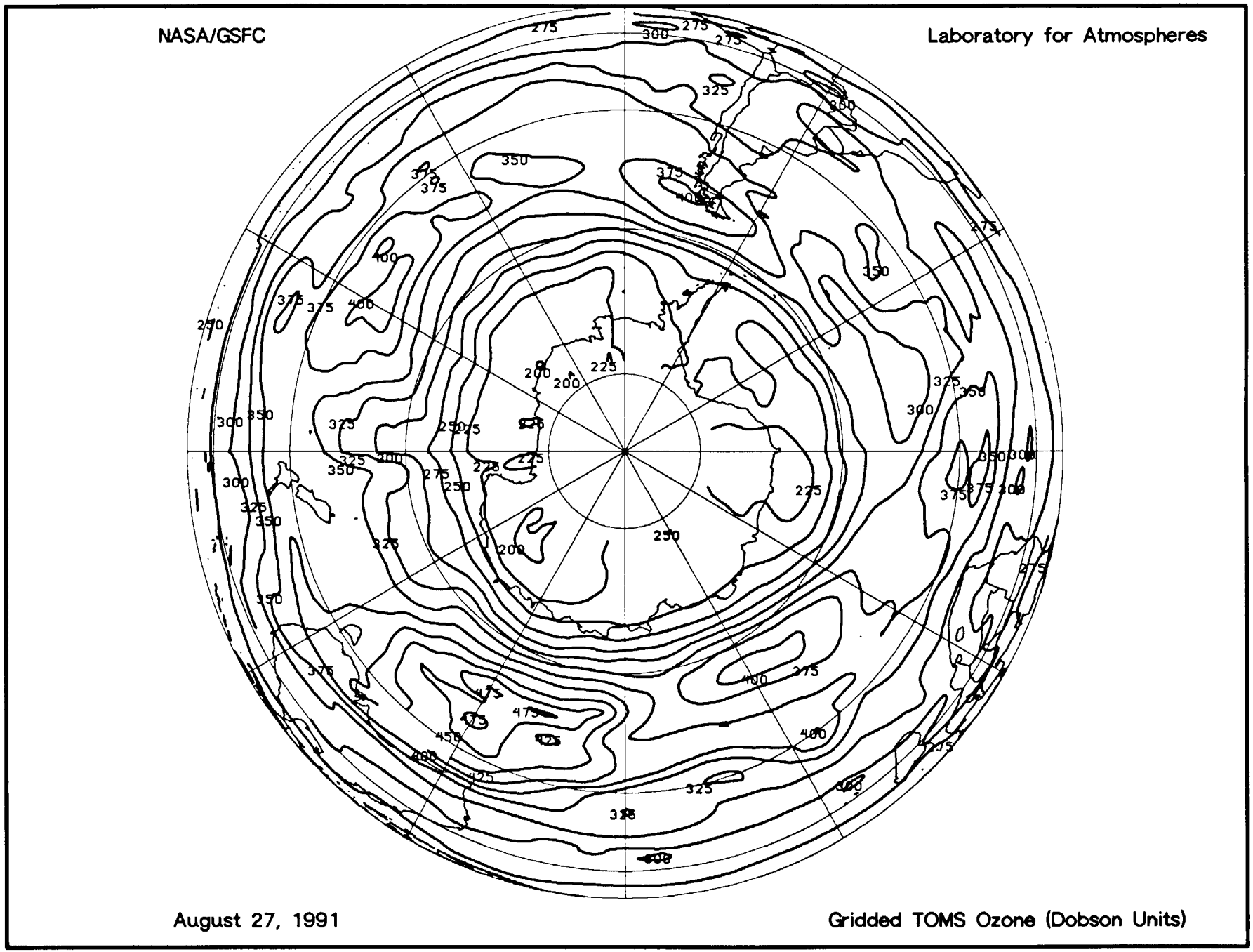
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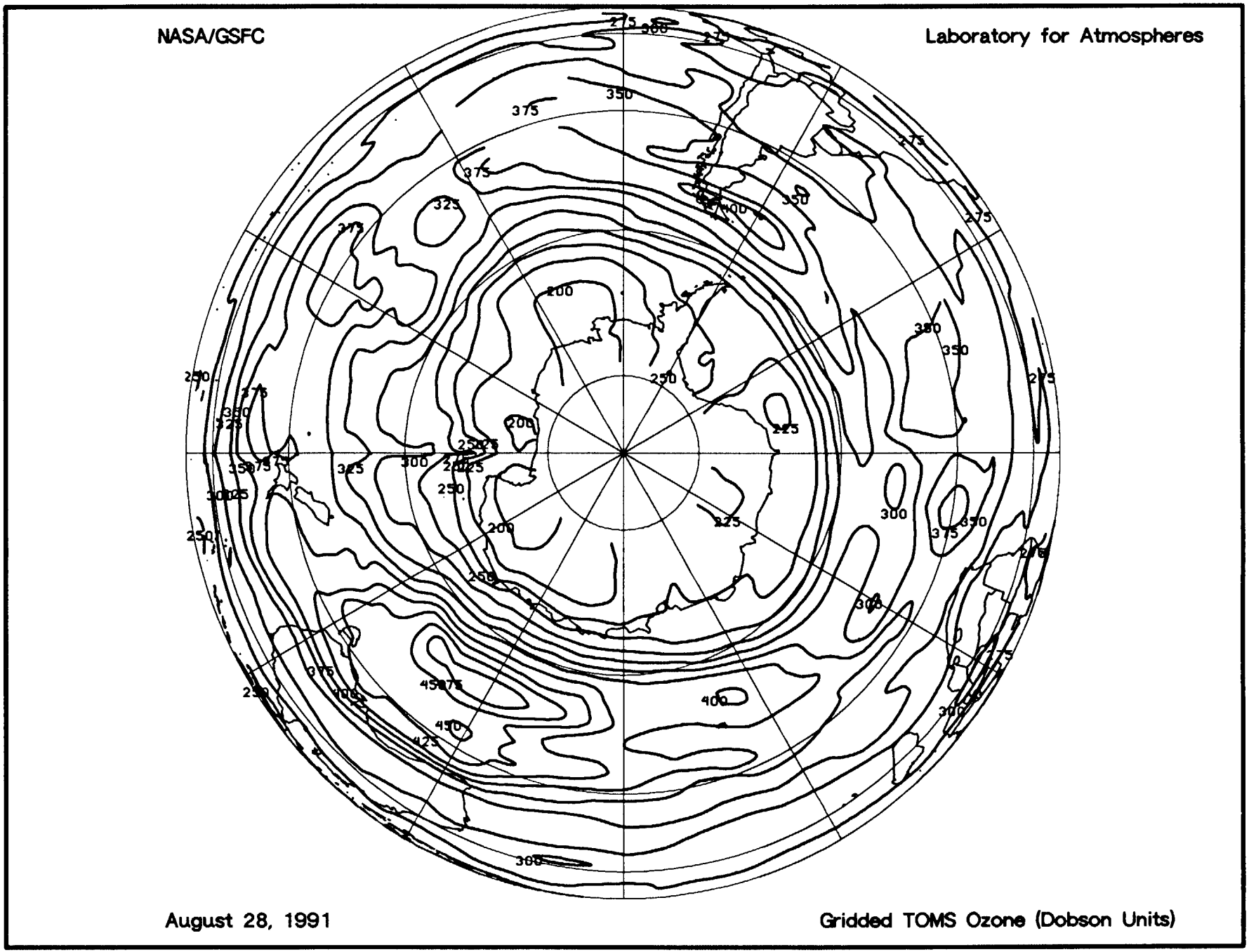
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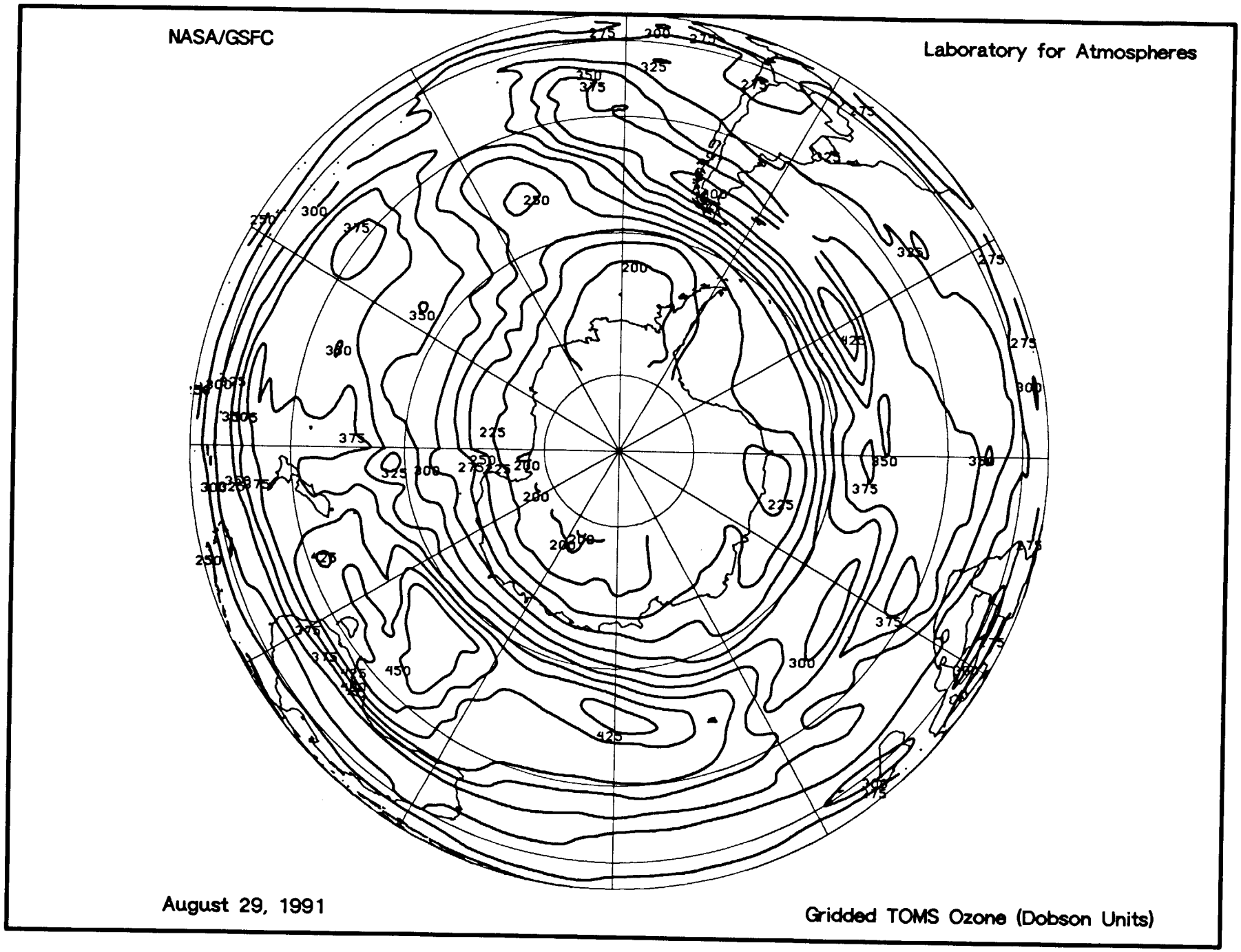
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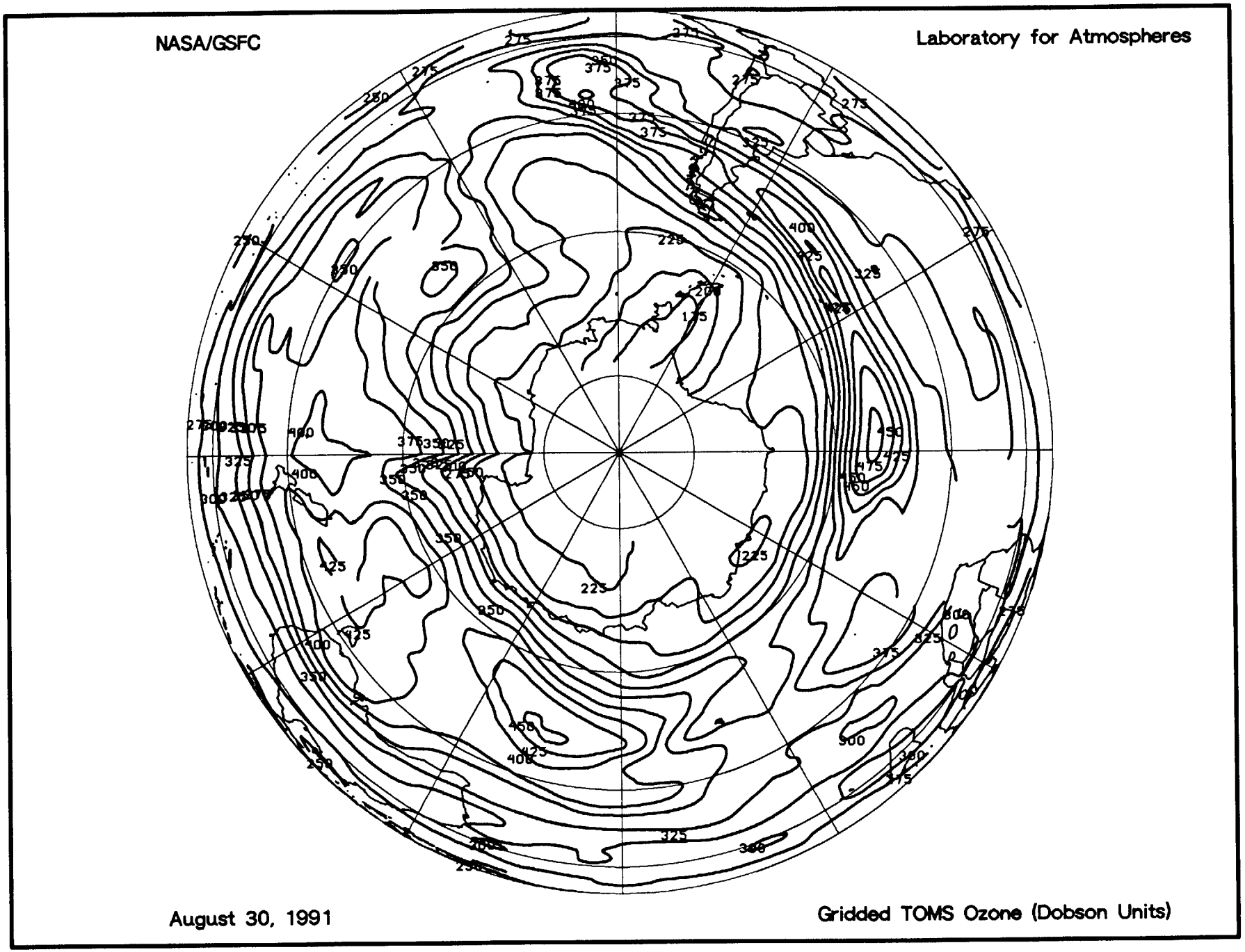
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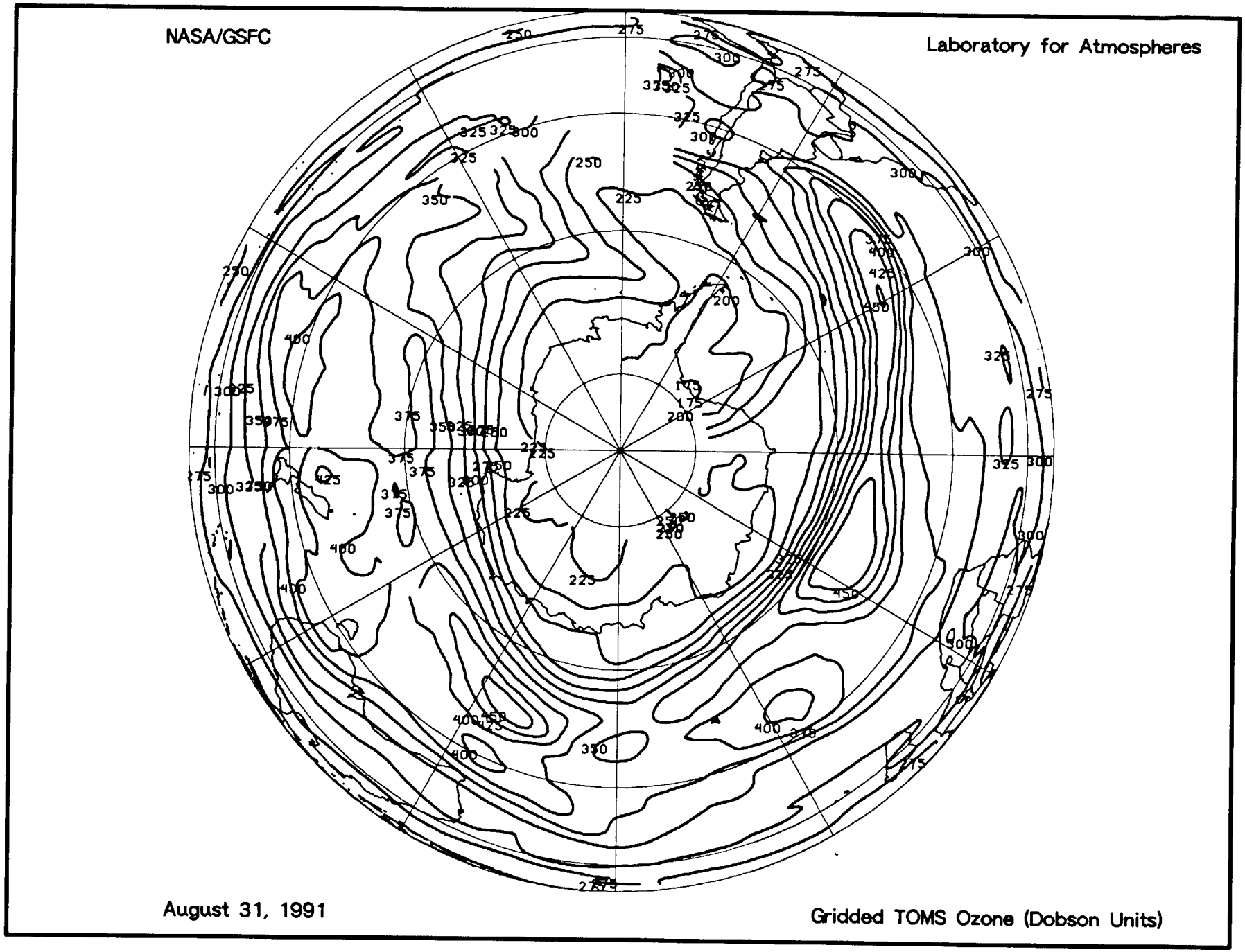
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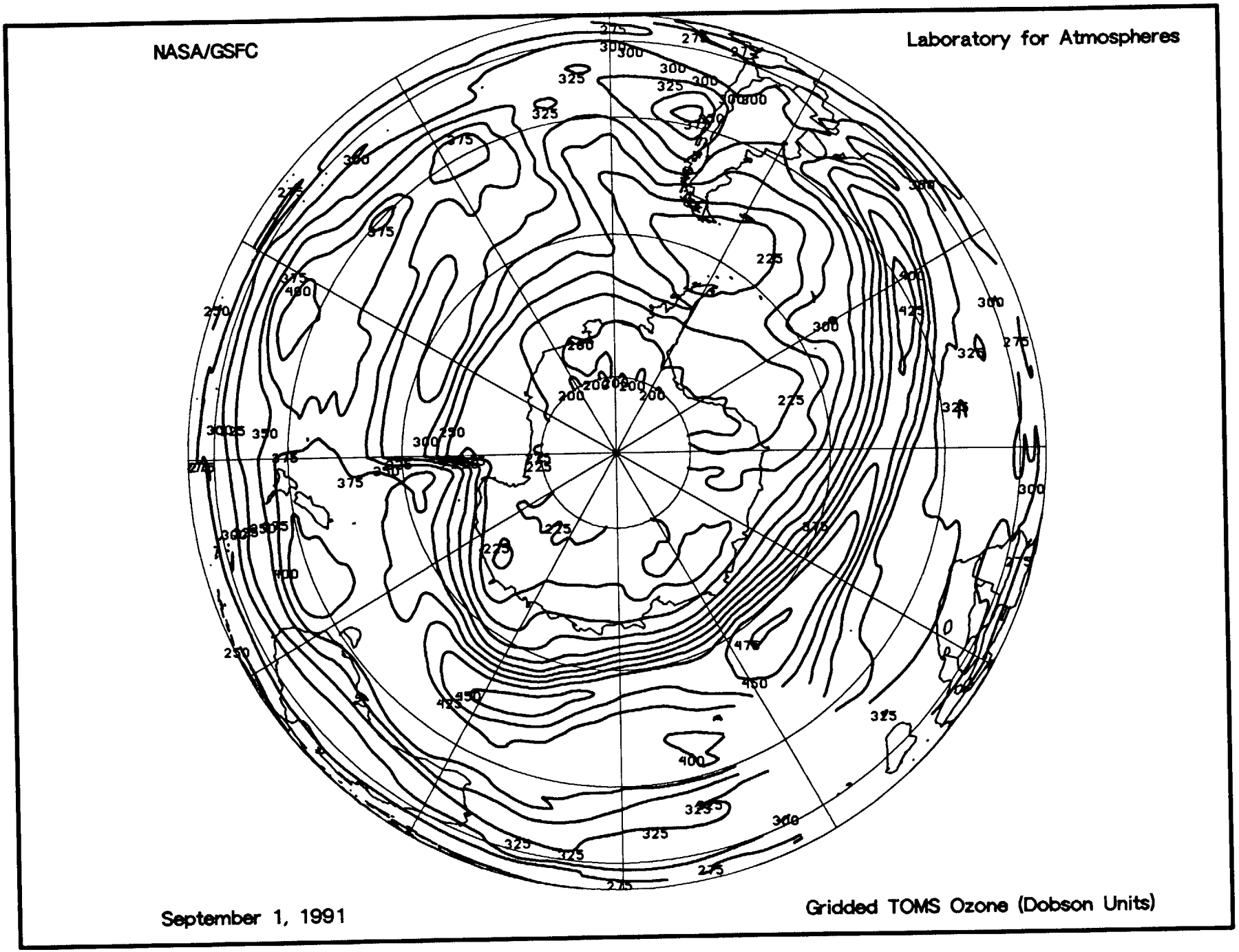
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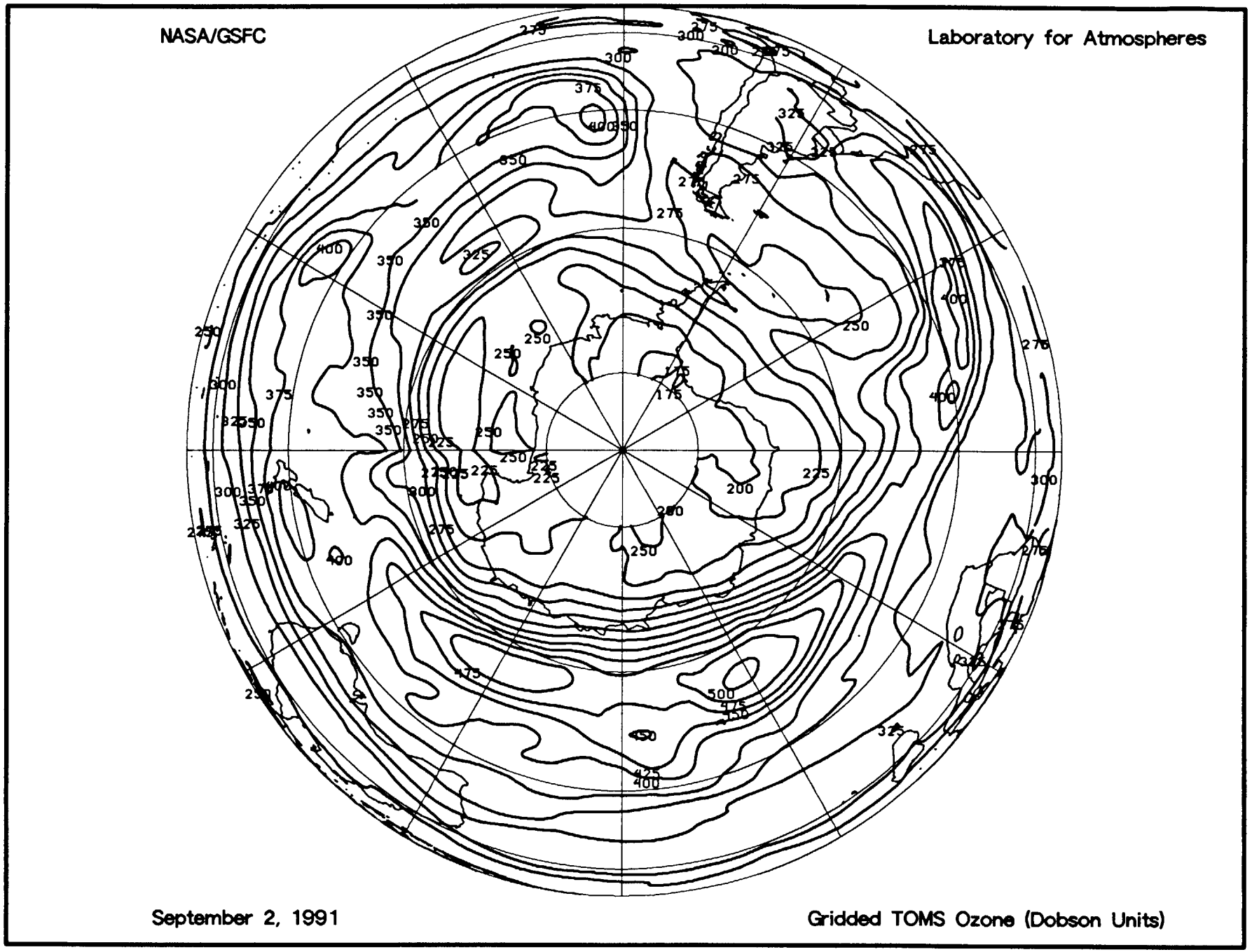
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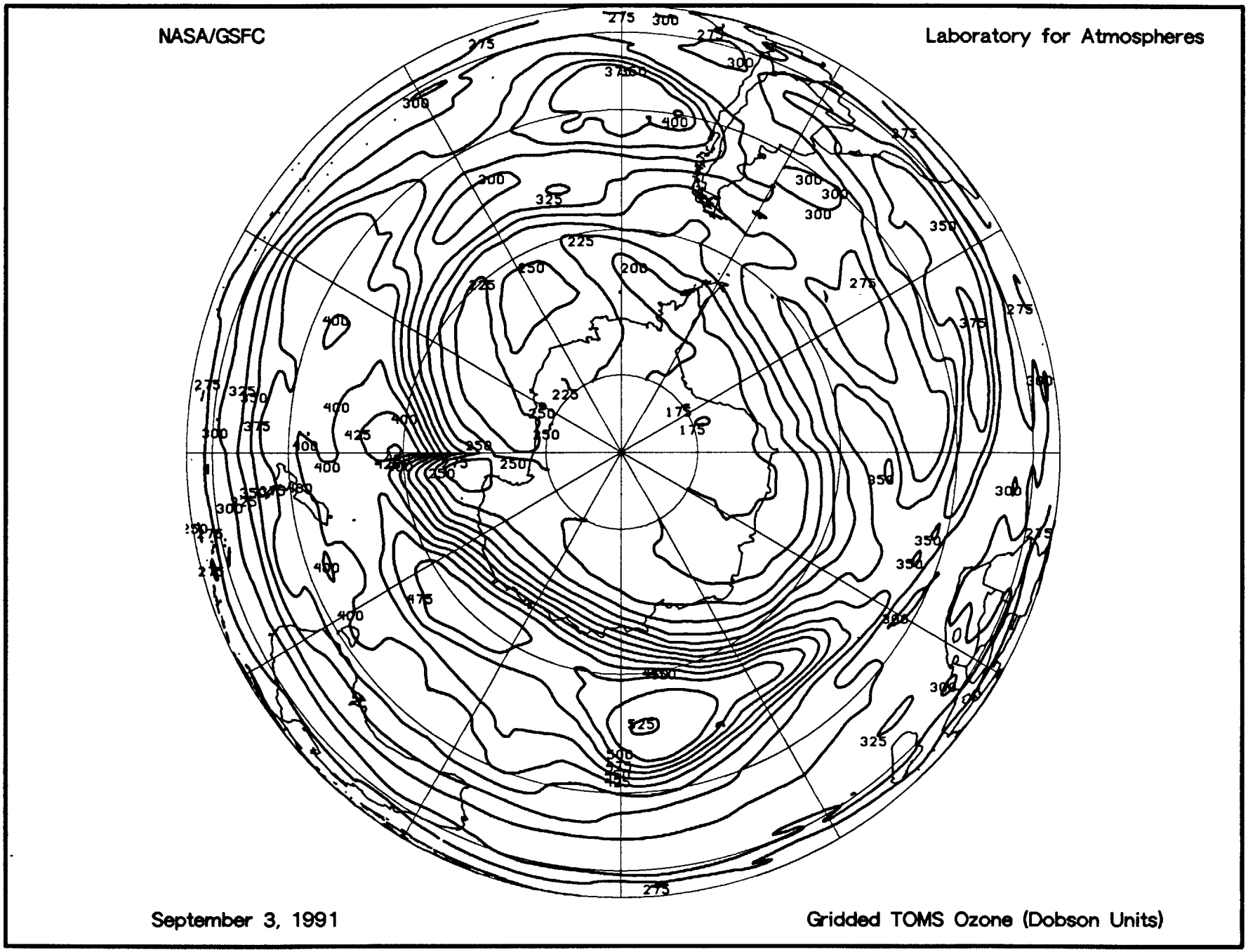
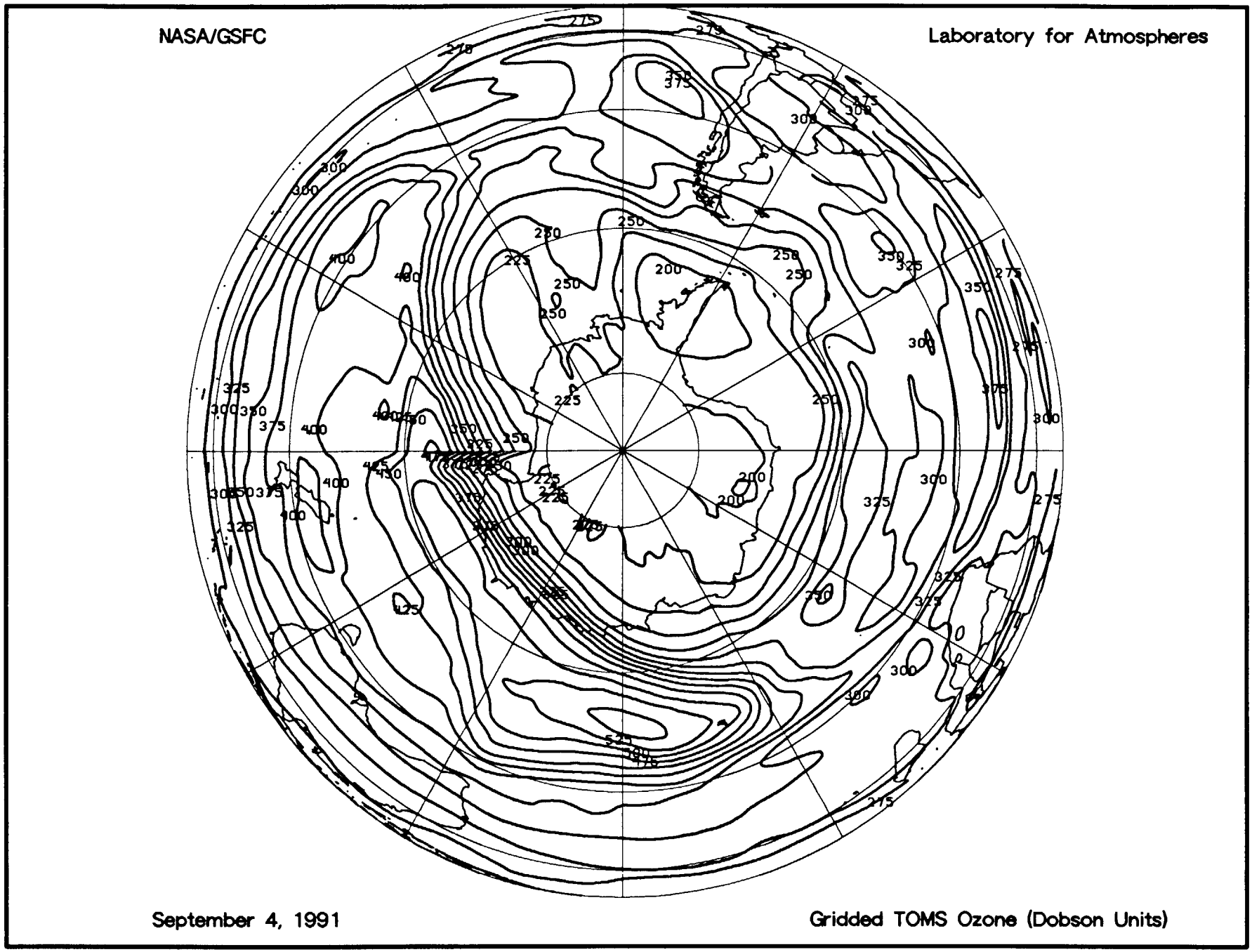
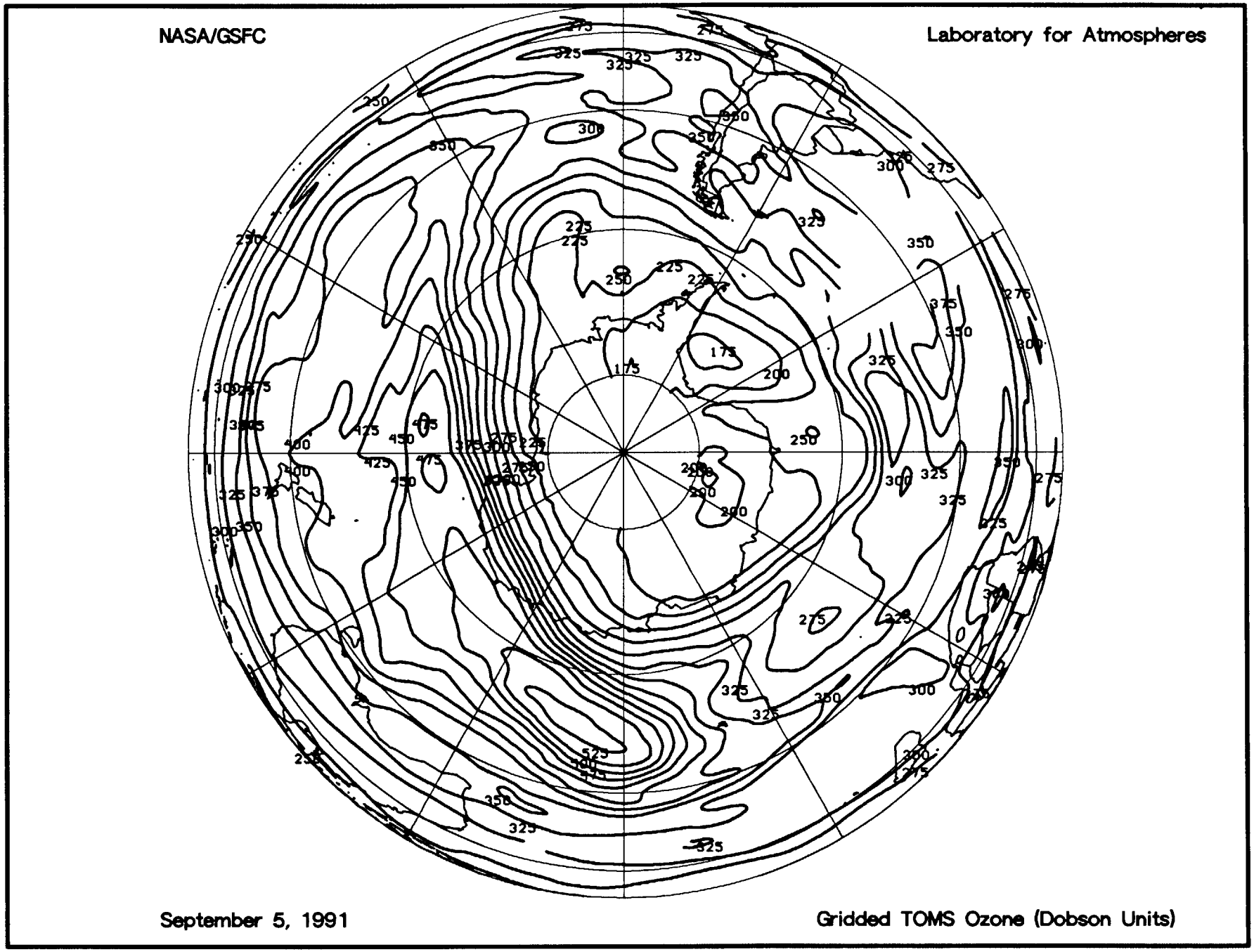
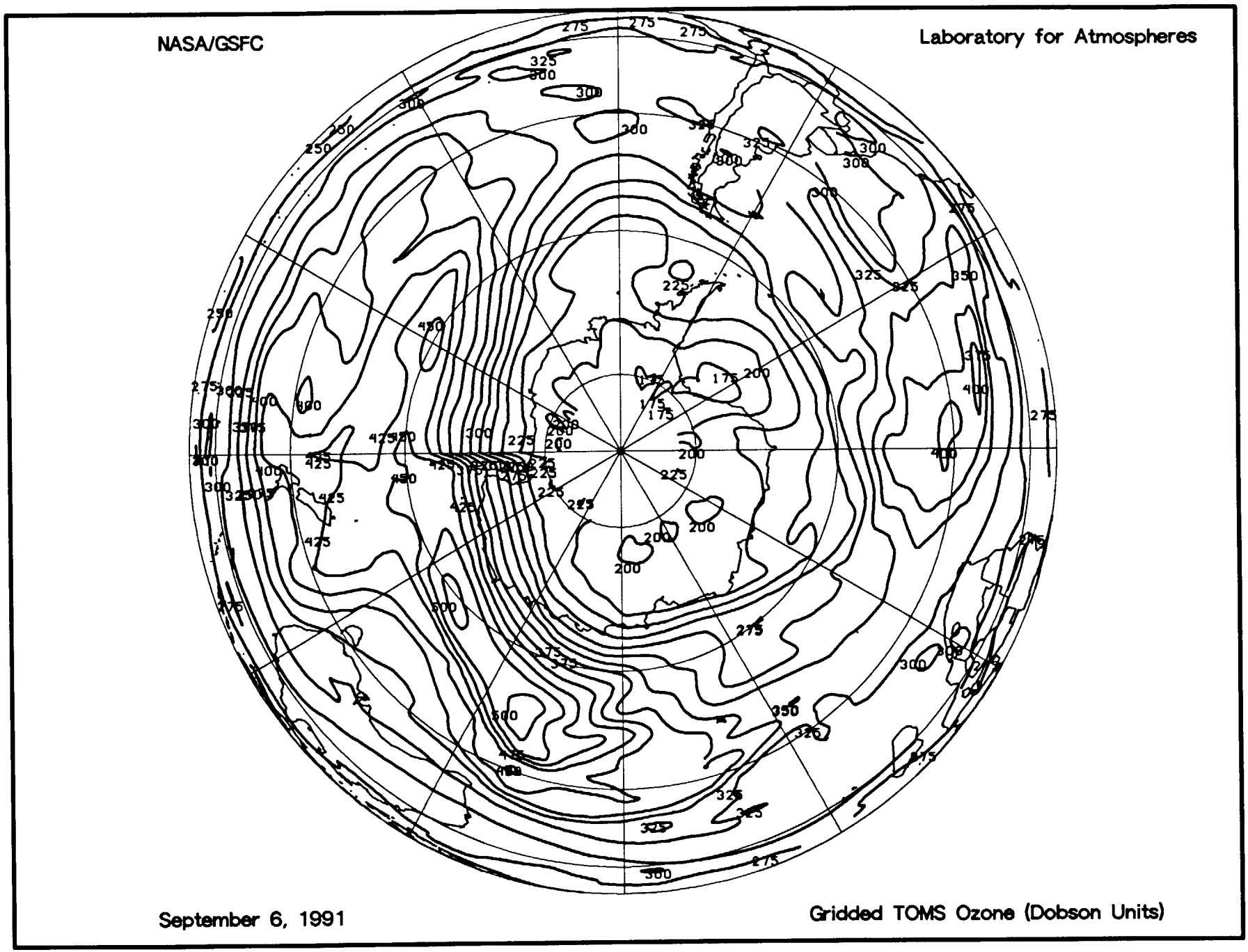
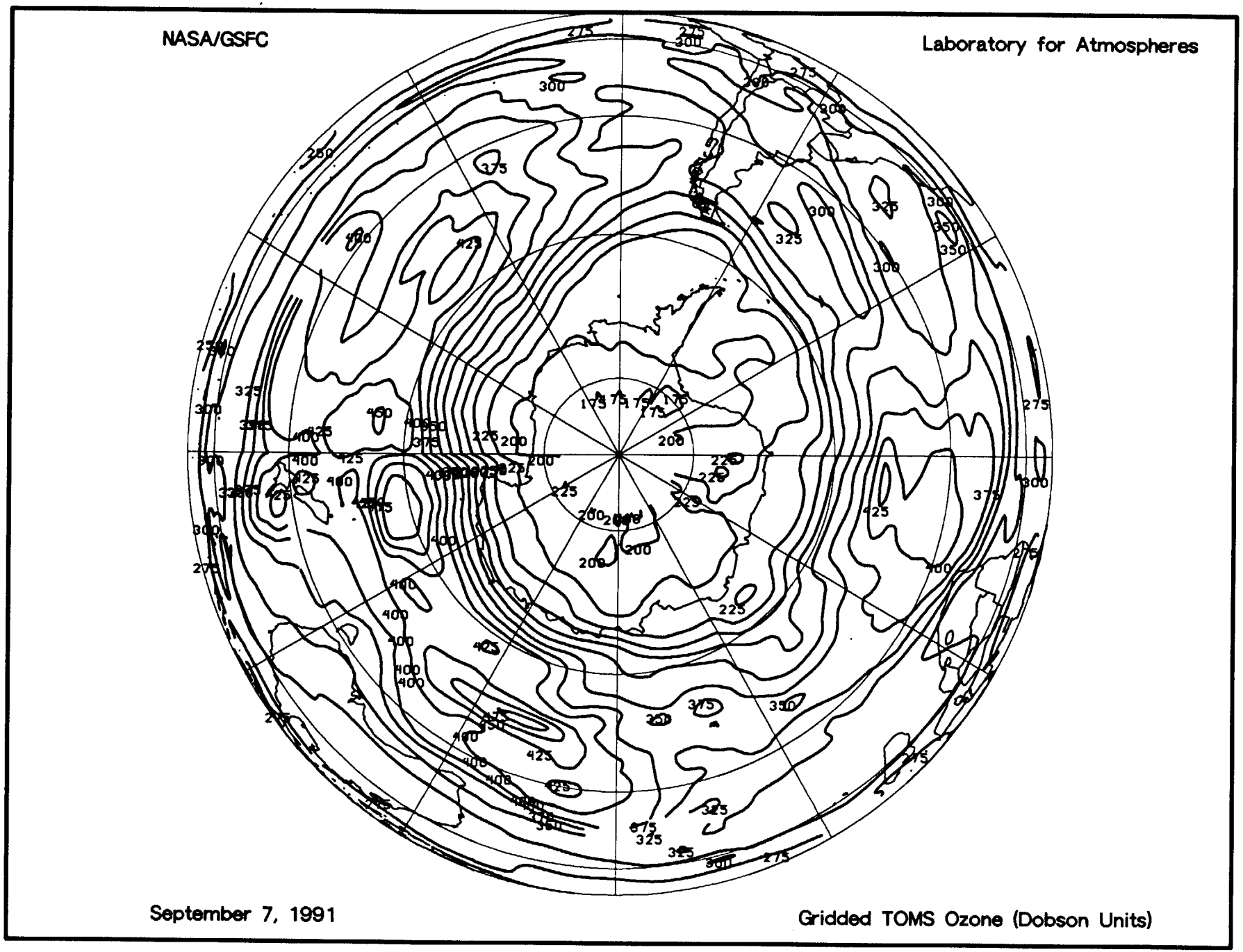
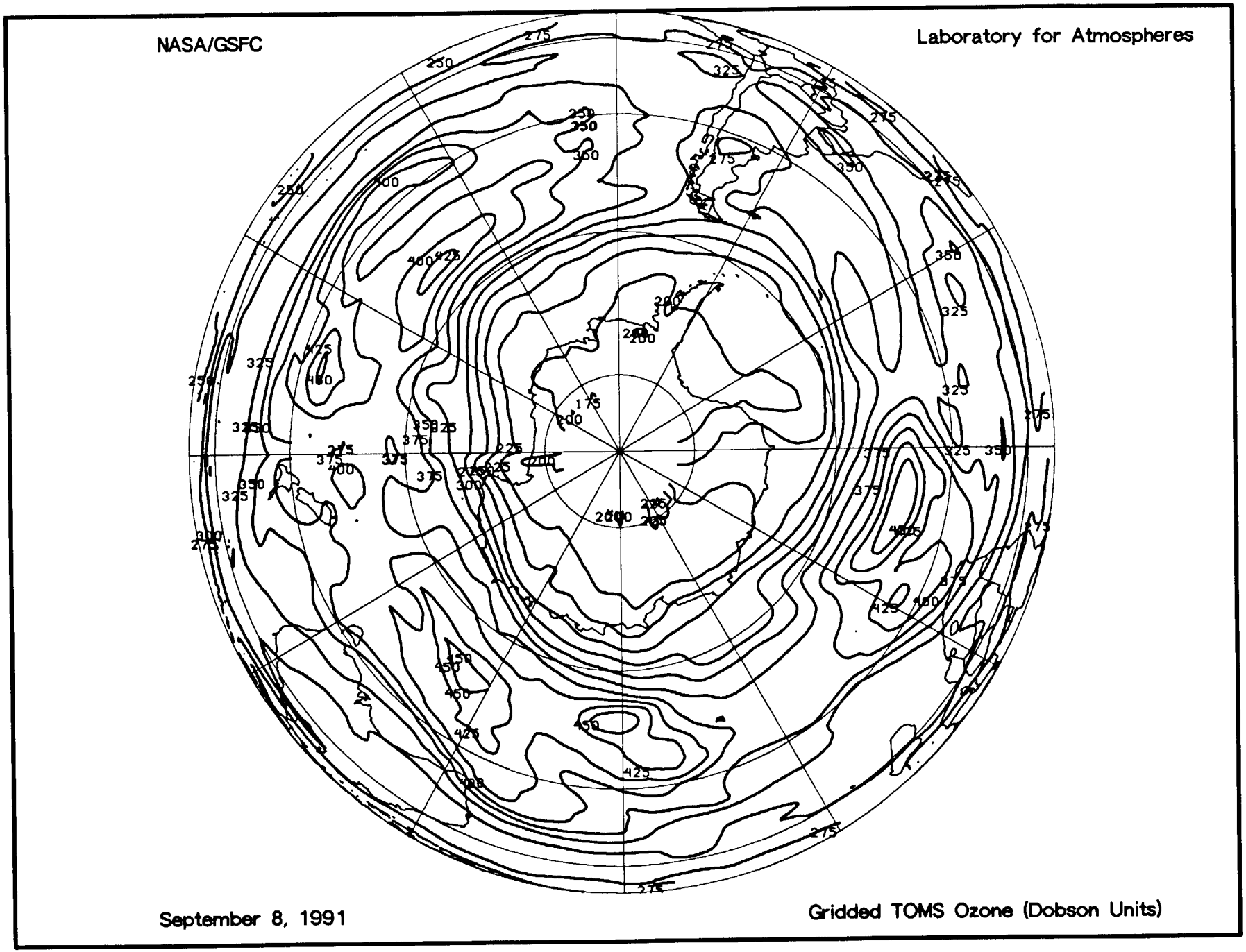

NASA/GSFC
Laboratory for Atmospheres
September 3, 1991
Gridded TOMS Ozone (Dobson Units)

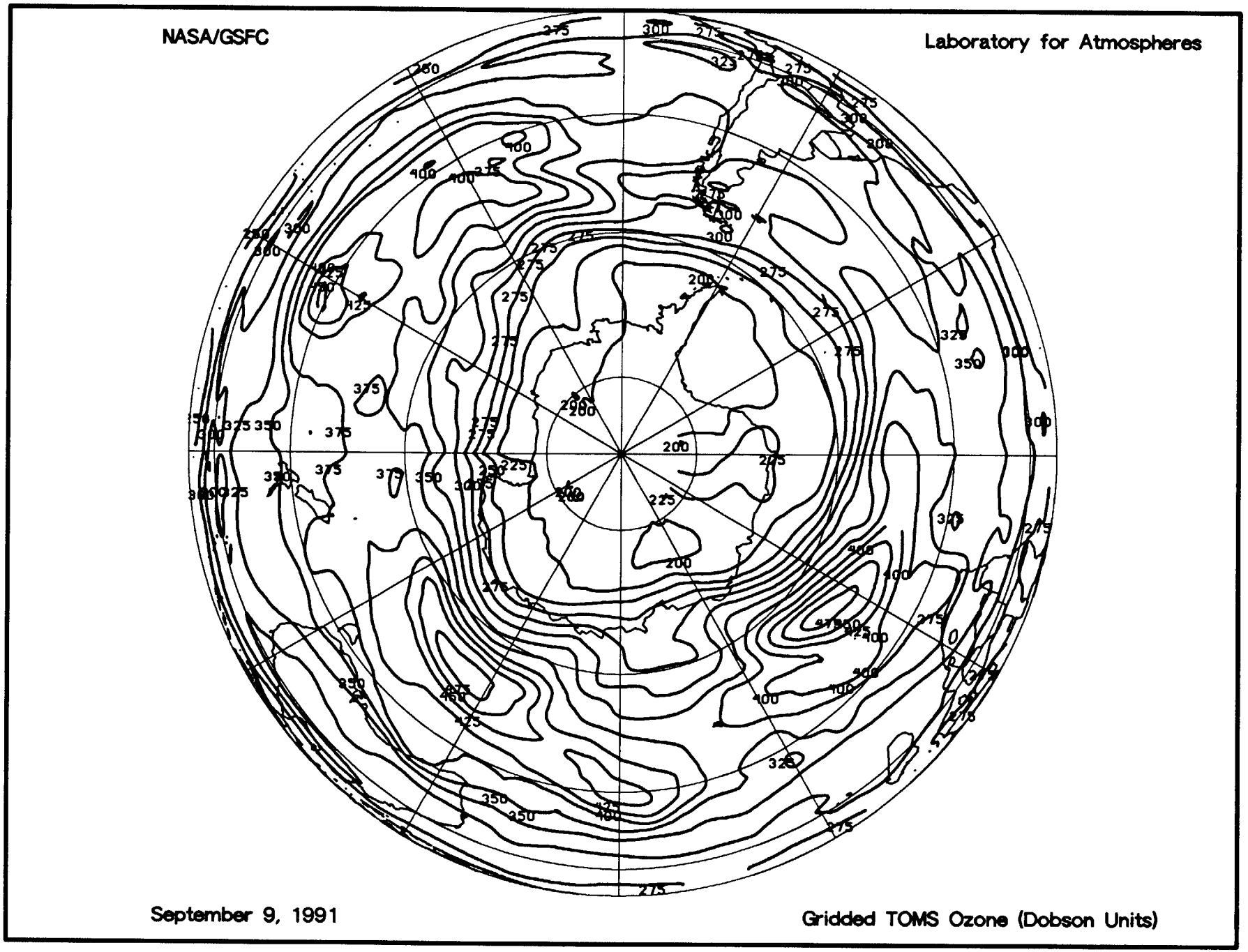

NASA/GSFC
Laboratory for Atmospheres
September 4, 1991
Gridded TOMS Ozone (Dobson Units)

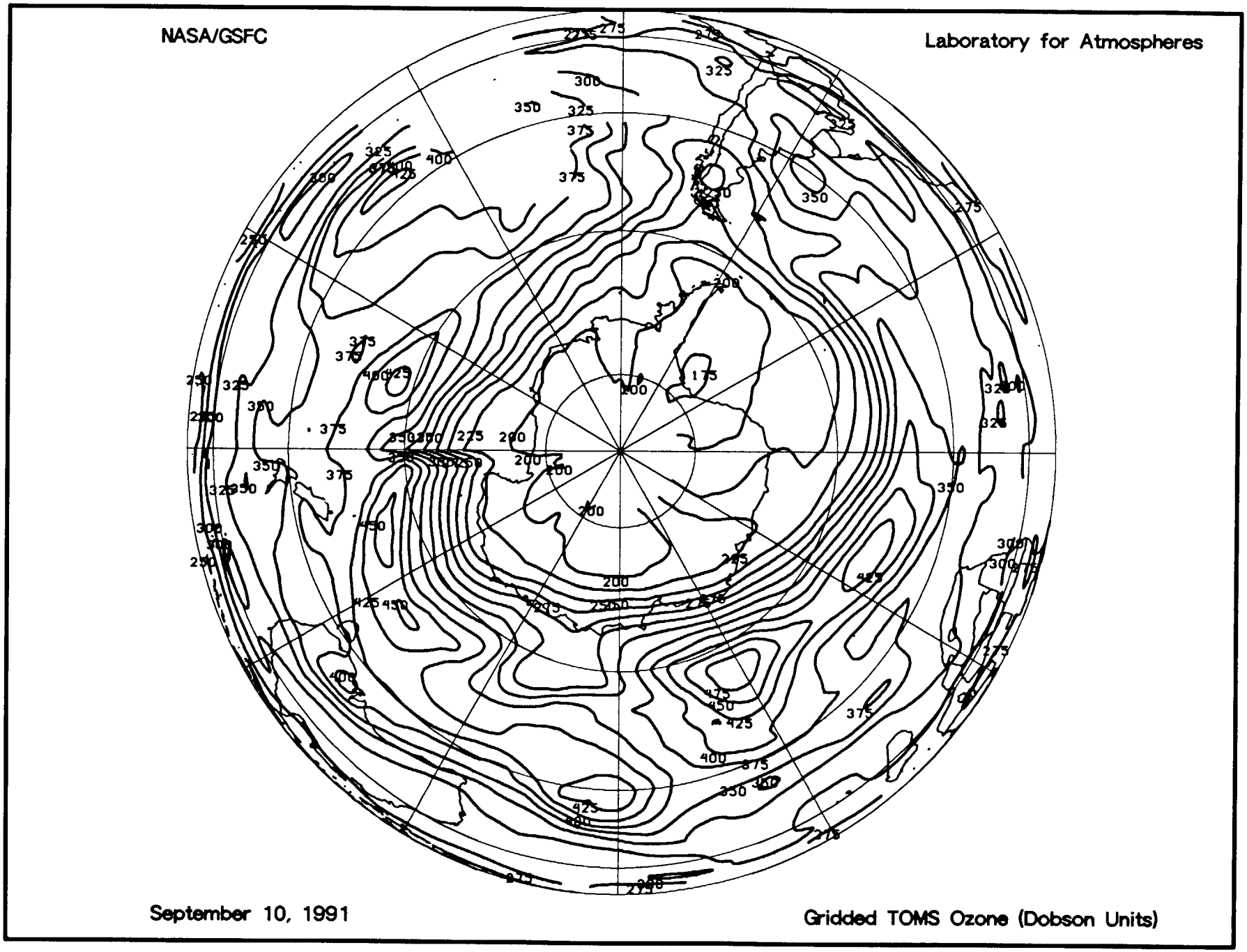

NASA/GSFC
Laboratory for Atmospheres
September 5, 1991
Gridded TOMS Ozone (Dobson Units)

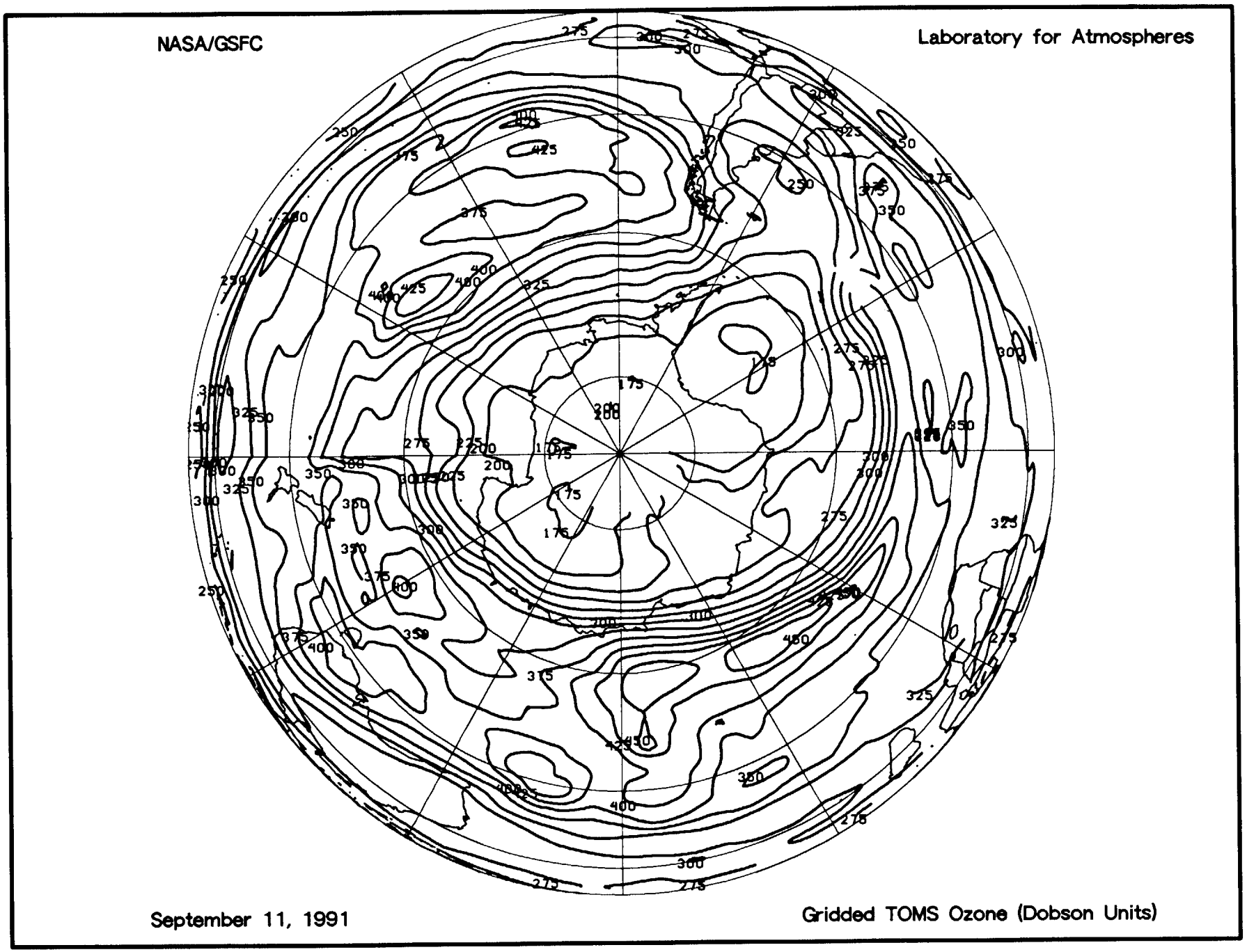

NASA/GSFC
Laboratory for Atmospheres
September 6, 1991
Gridded TOMS Ozone (Dobson Units)

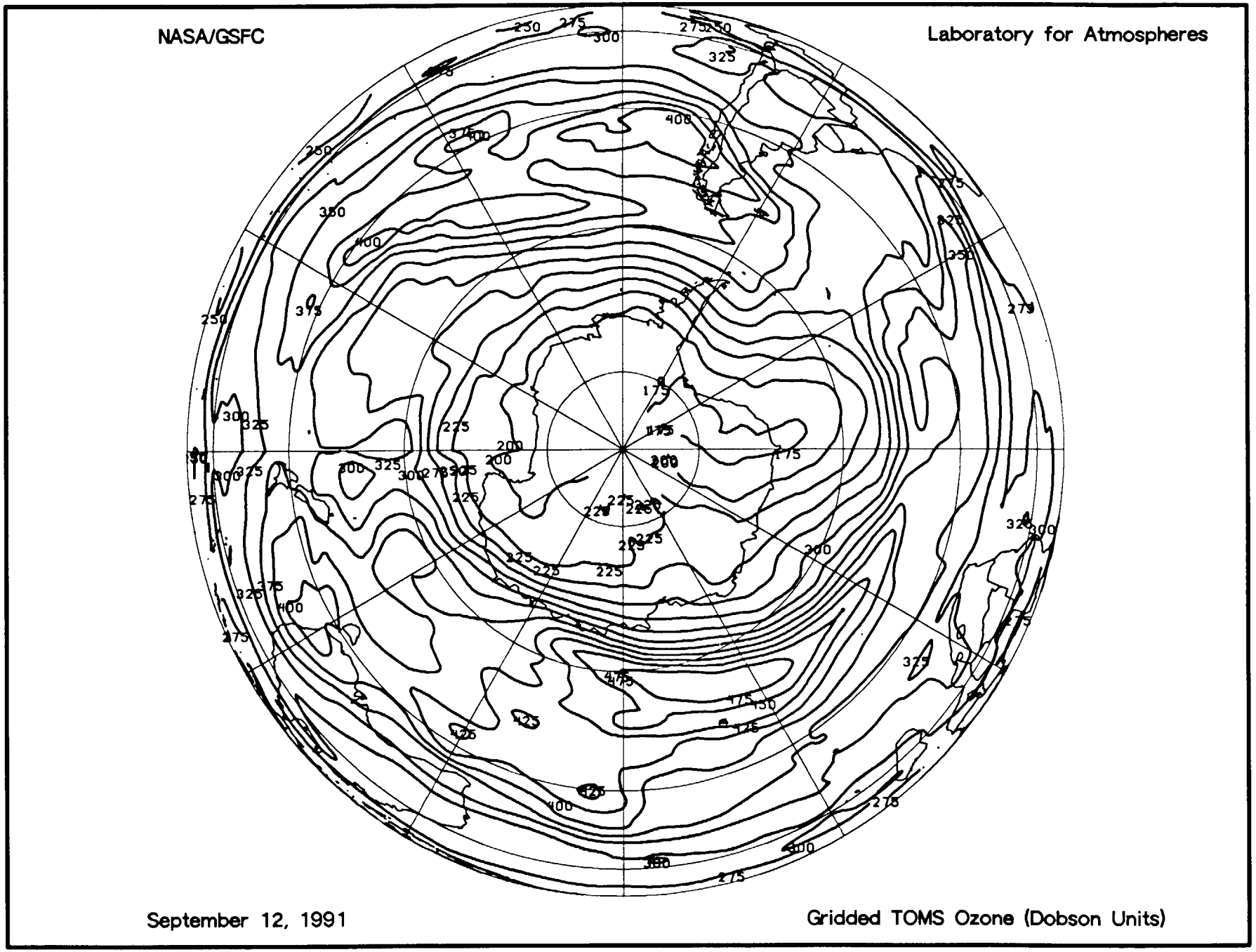

NASA/GSFC
Laboratory for Atmospheres
September 7, 1991
Gridded TOMS Ozone (Dobson Units)

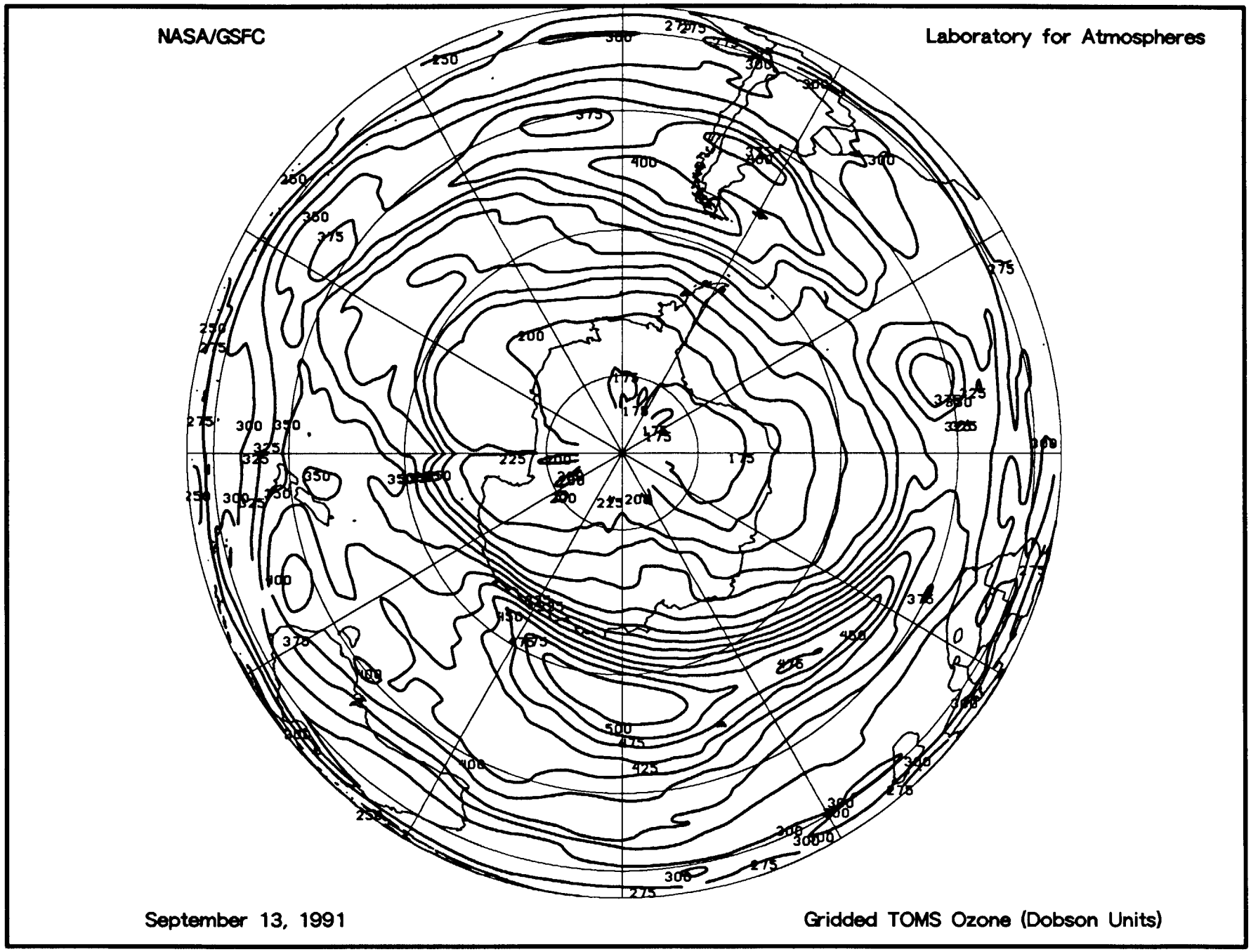

NASA/GSFC
Laboratory for Atmospheres
September 8, 1991
Gridded TOMS Ozone (Dobson Units)

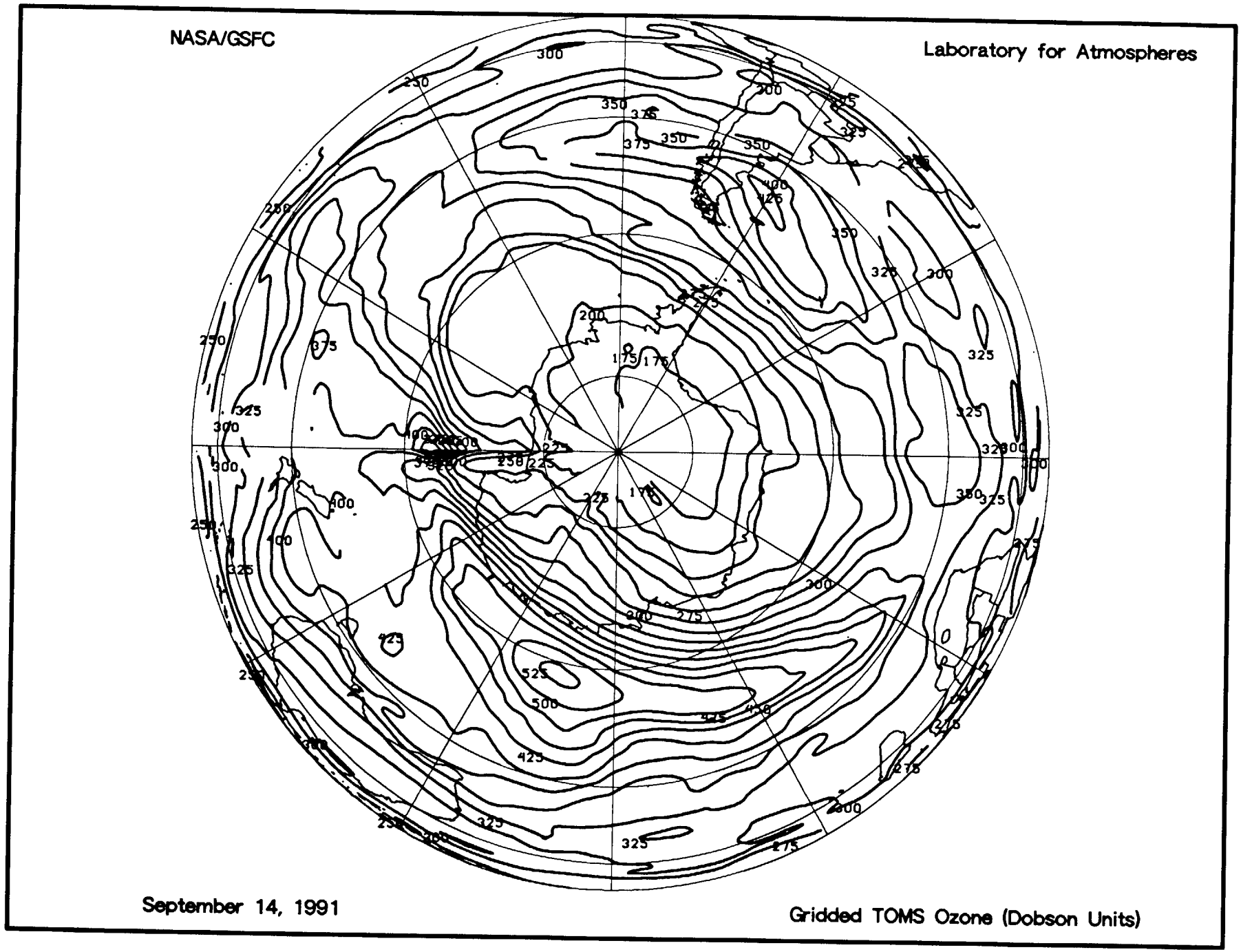

NASA/GSFC
Laboratory for Atmospheres
September 9, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 10, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 11, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 12, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 13, 1991
Gridded TOMS Ozone (Dobson Units)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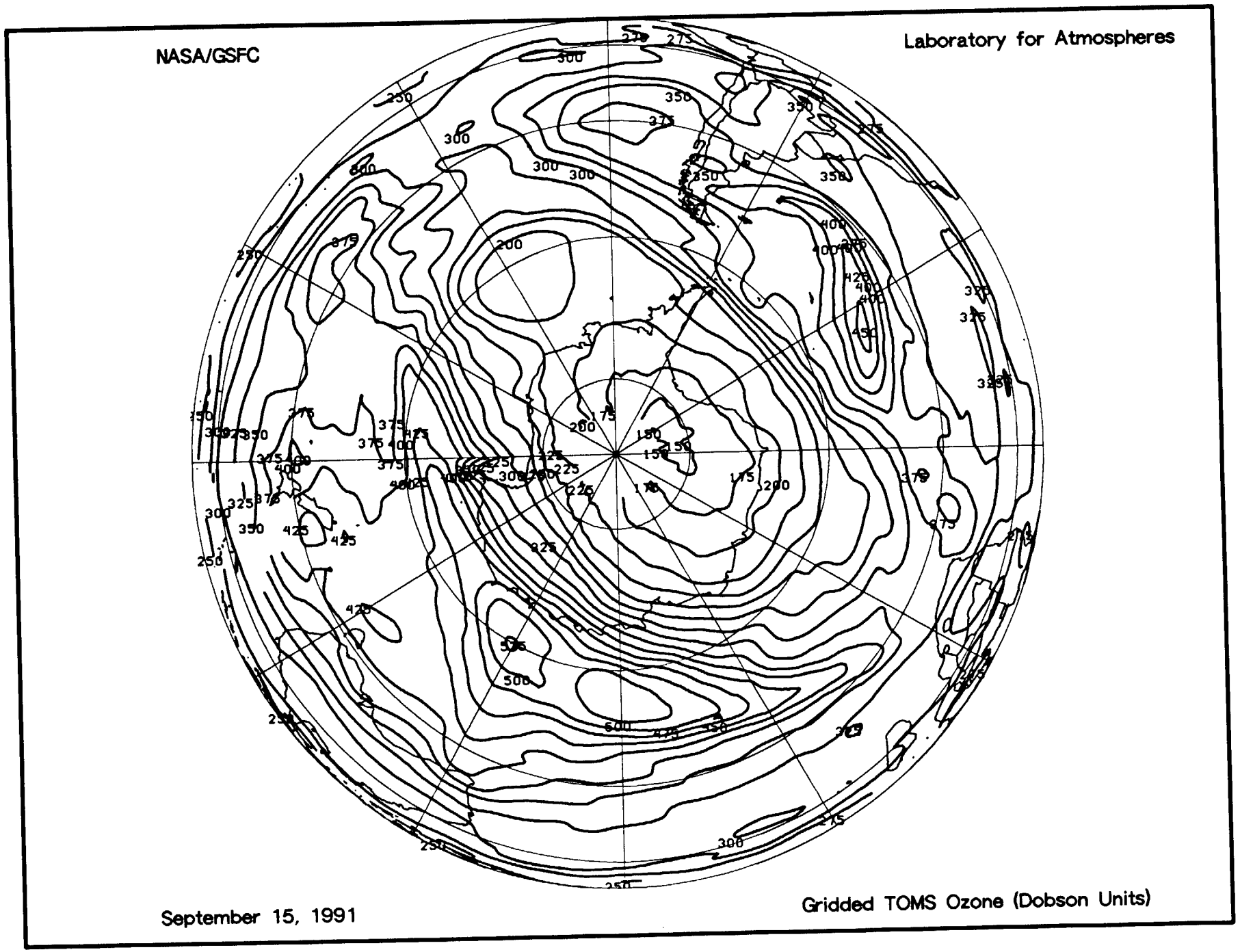
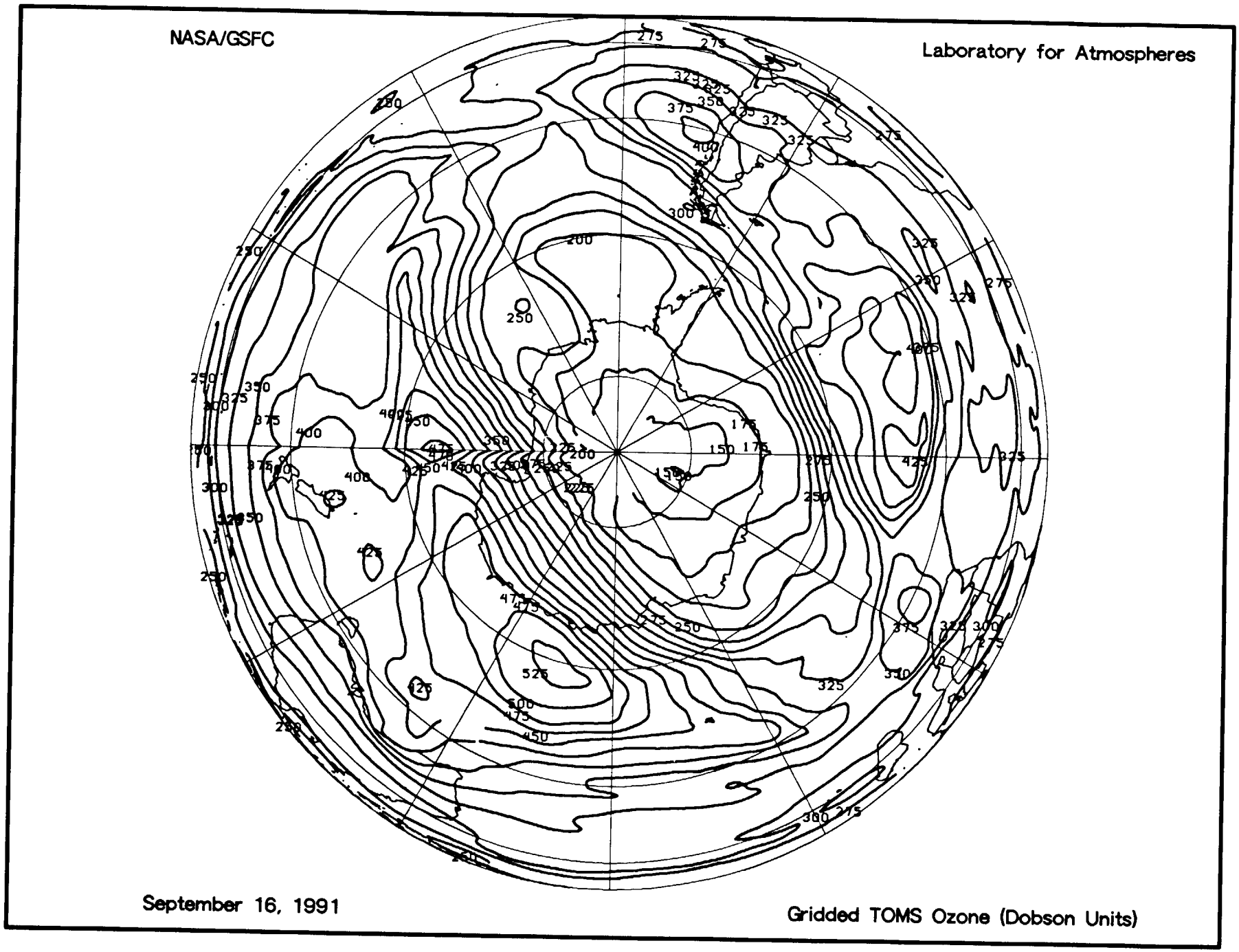
Laboratory for Atmospheres
September 14, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 15, 1991
Gridded TOMS Ozone (Dobson Units)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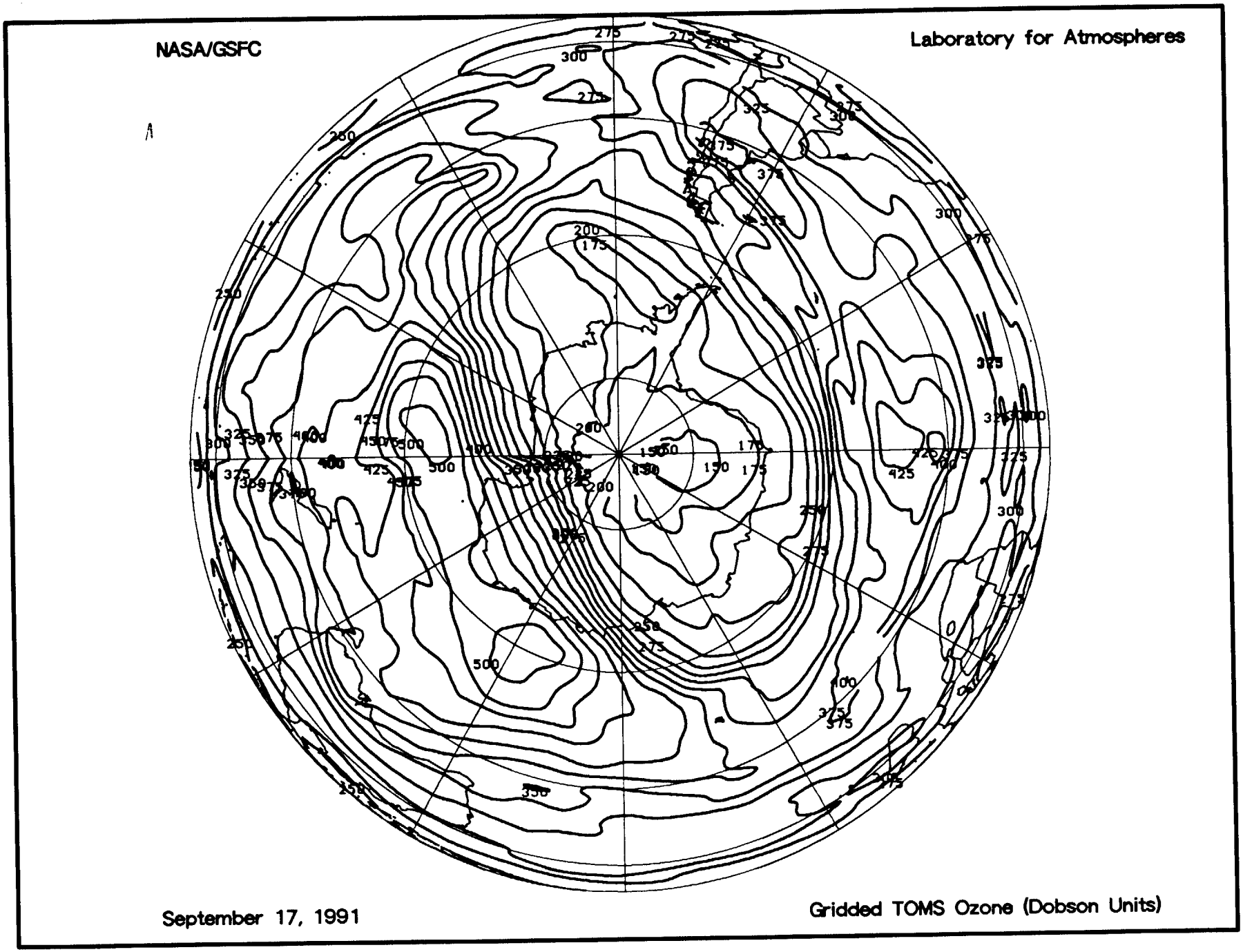
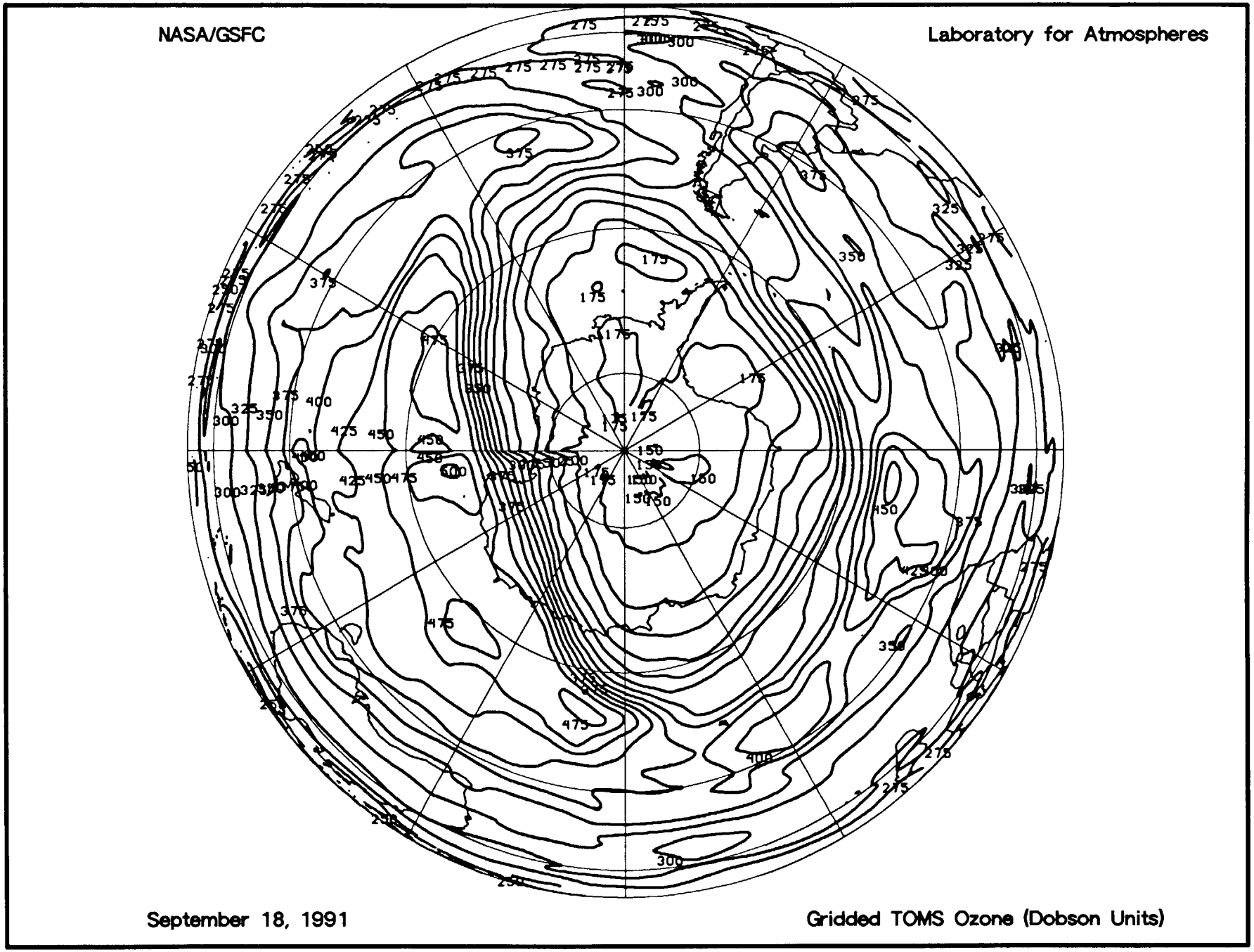
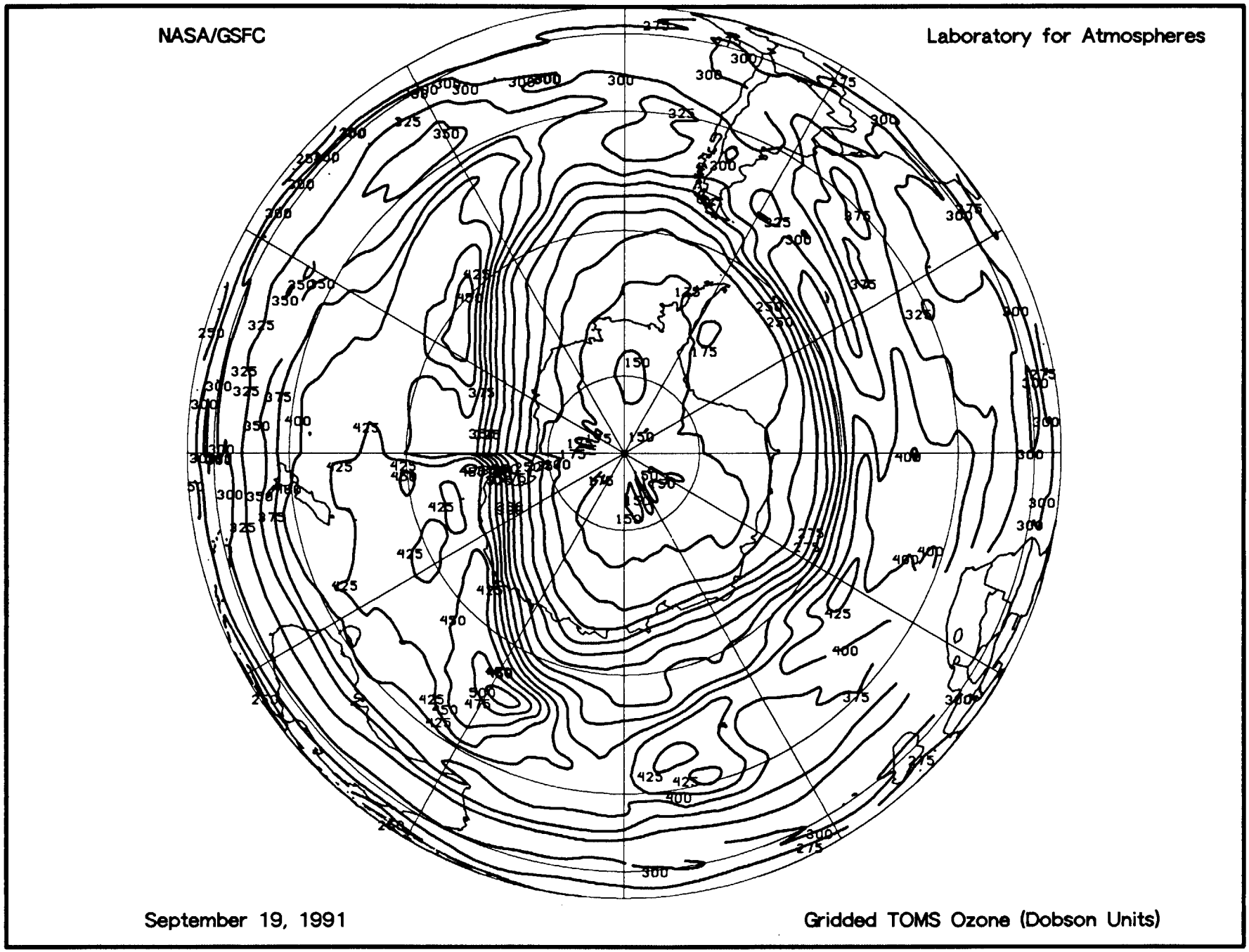
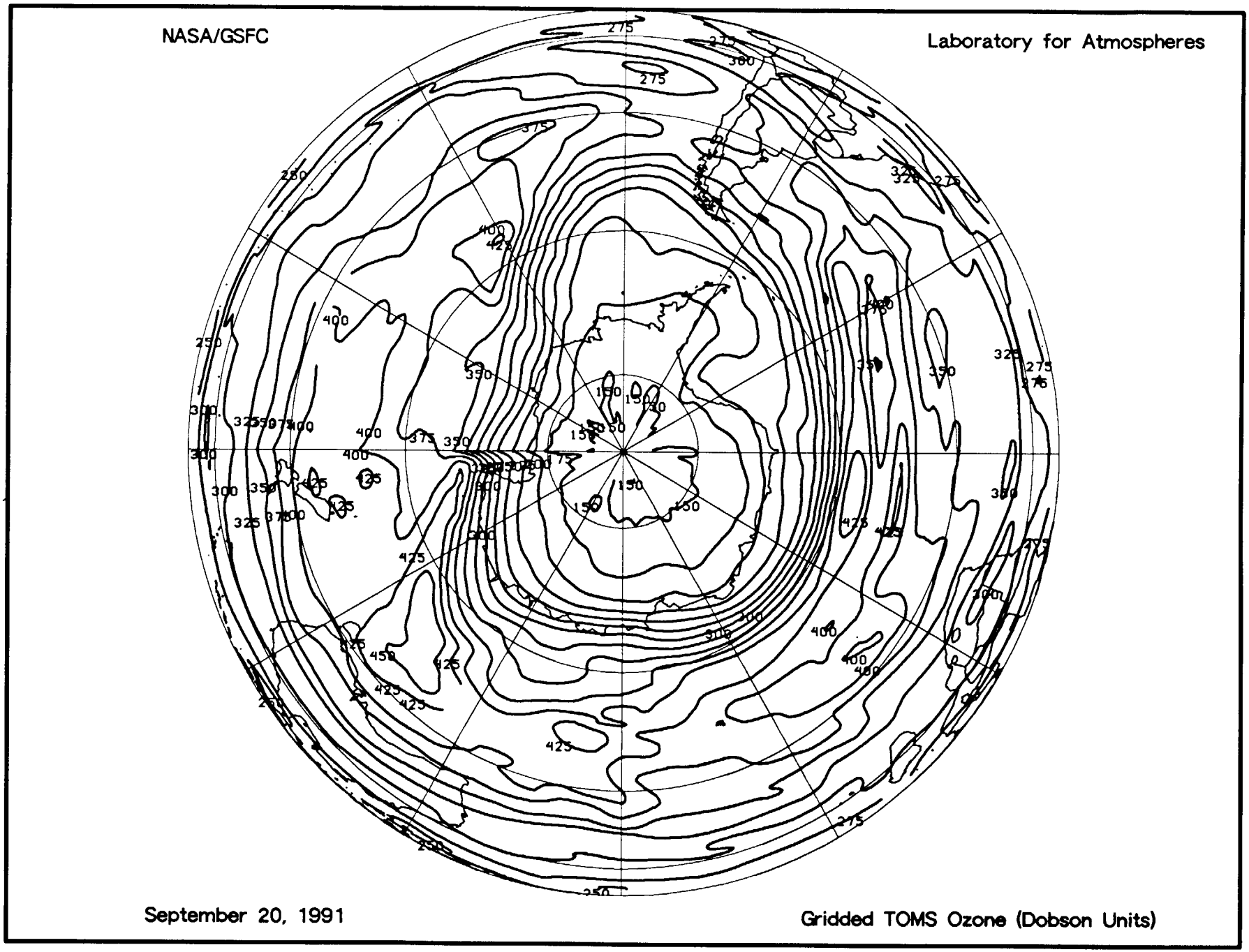
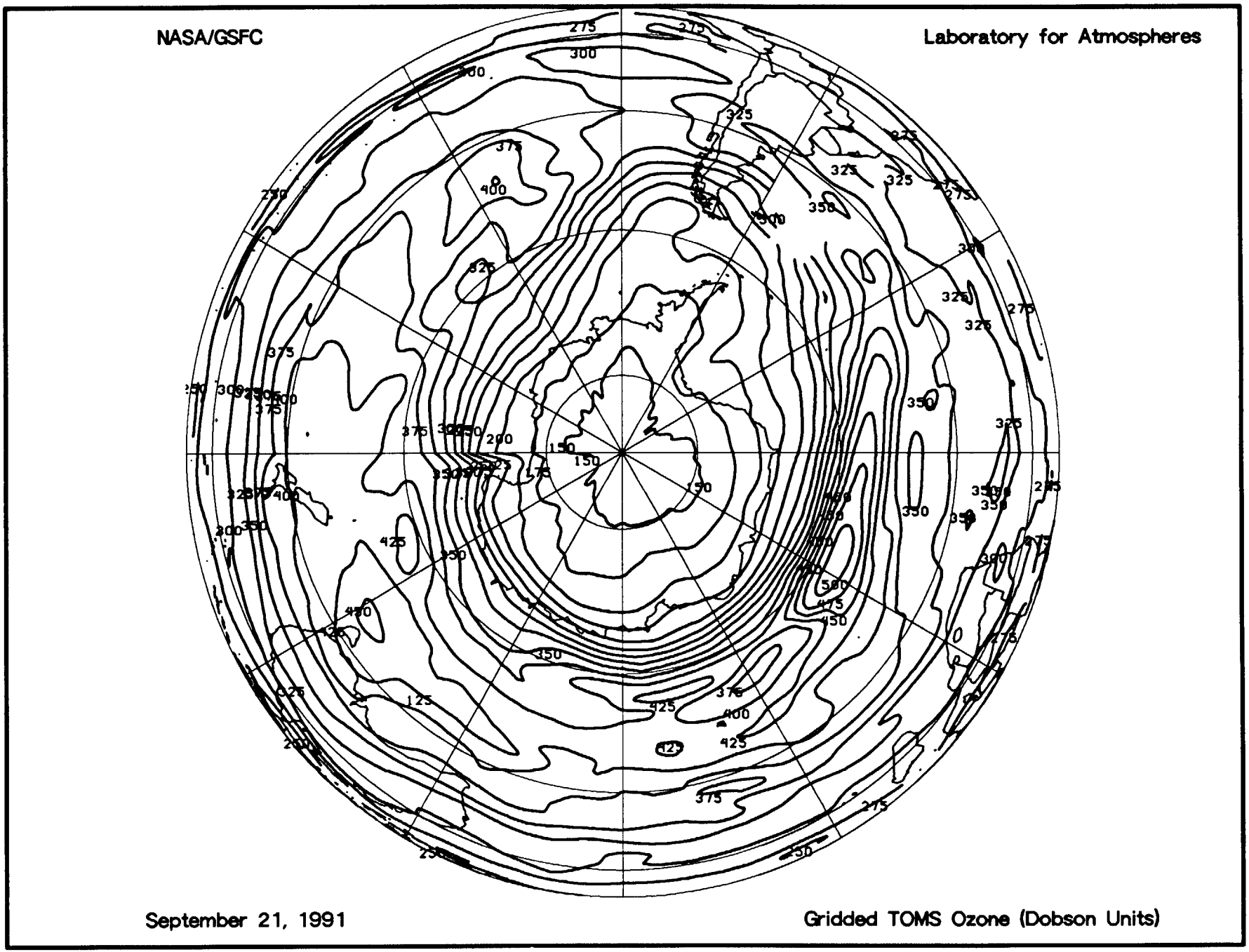
Laboratory for Atmospheres
September 16, 1991
Gridded TOMS Ozone (Dobson Units)

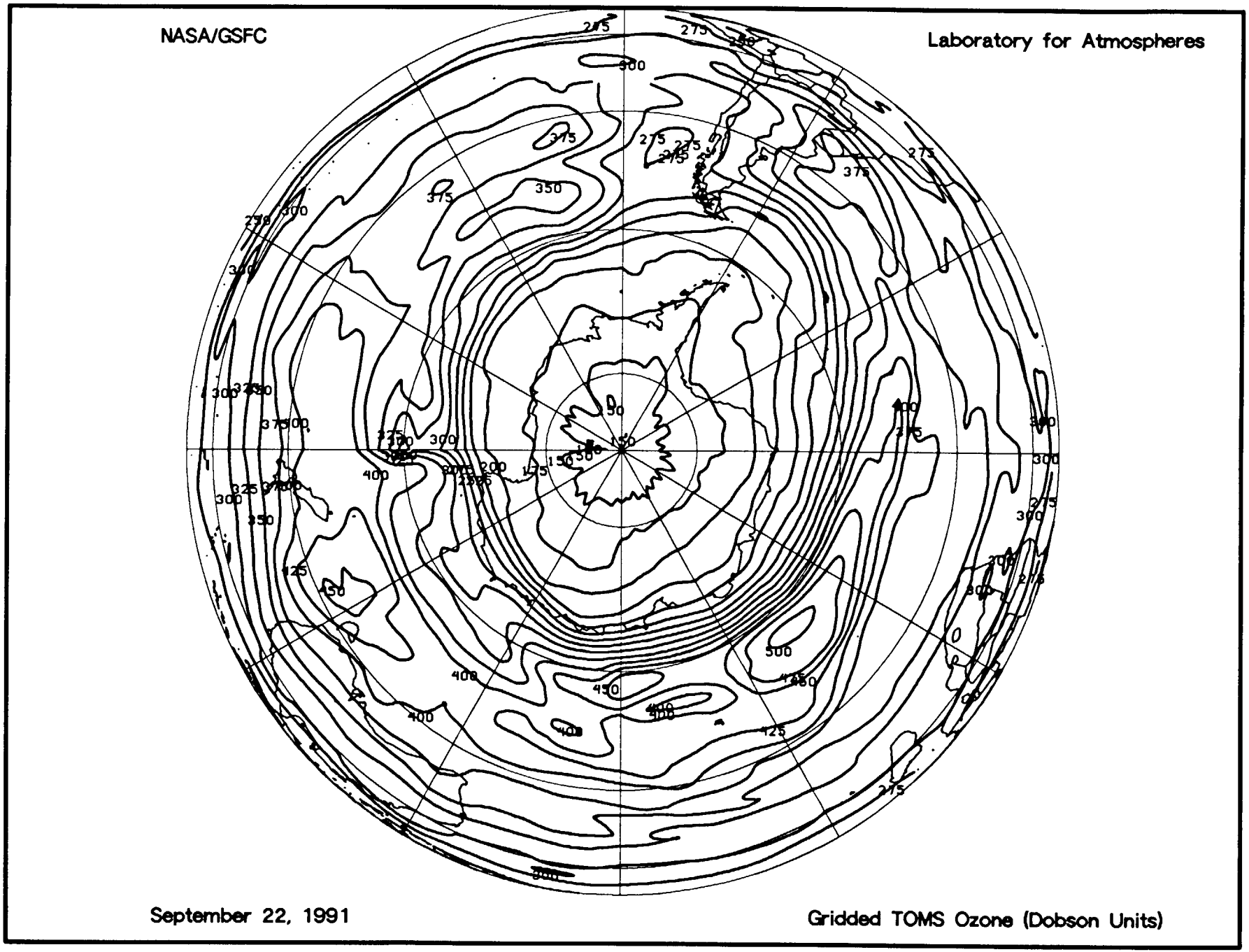

NASA/GSFC
Laboratory for Atmospheres
September 17, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 18, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 19, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 20, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 21, 1991
Gridded TOMS Ozone (Dobson Units)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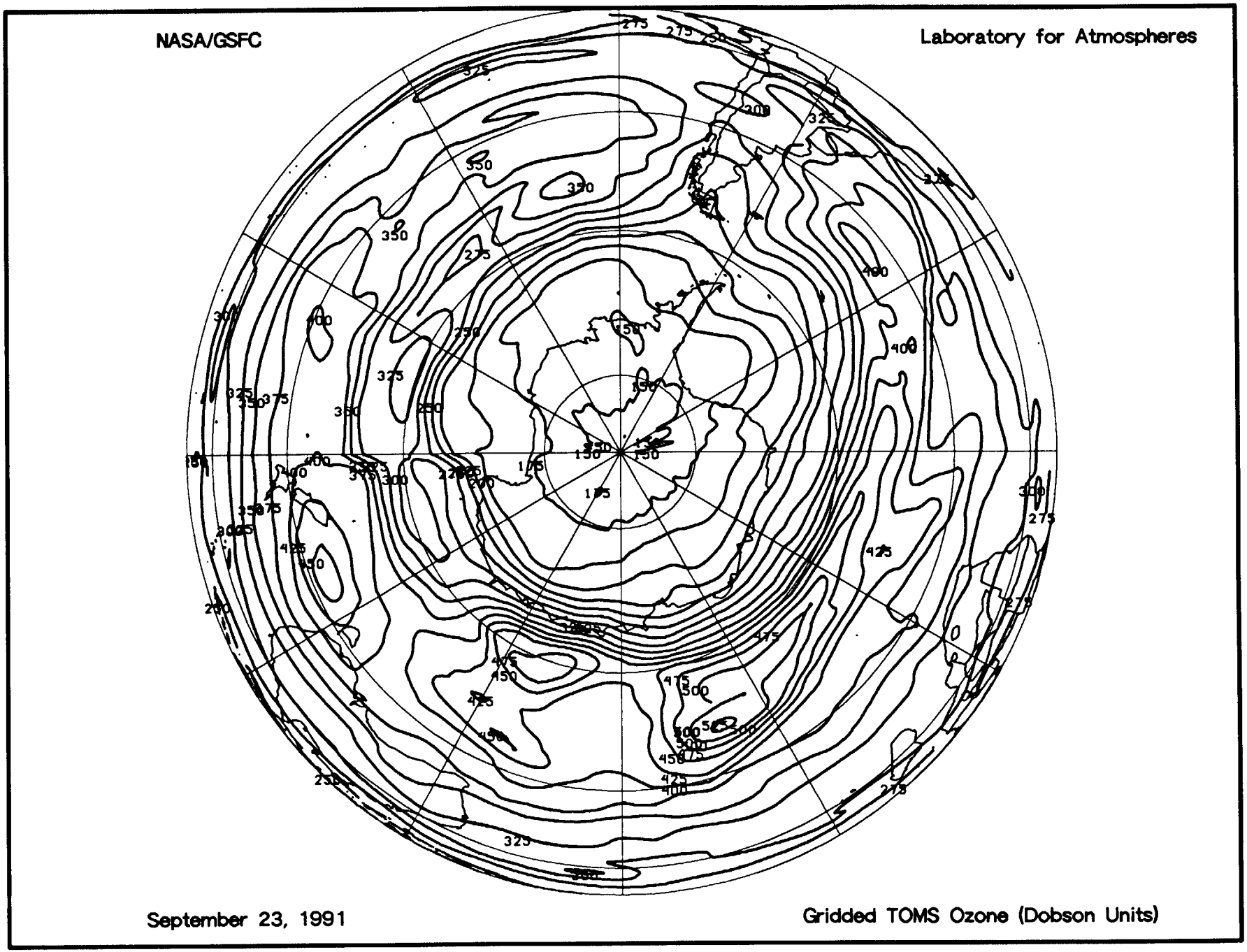
Laboratory for Atmospheres
September 22, 1991
Gridded TOMS Ozone (Dobson Units)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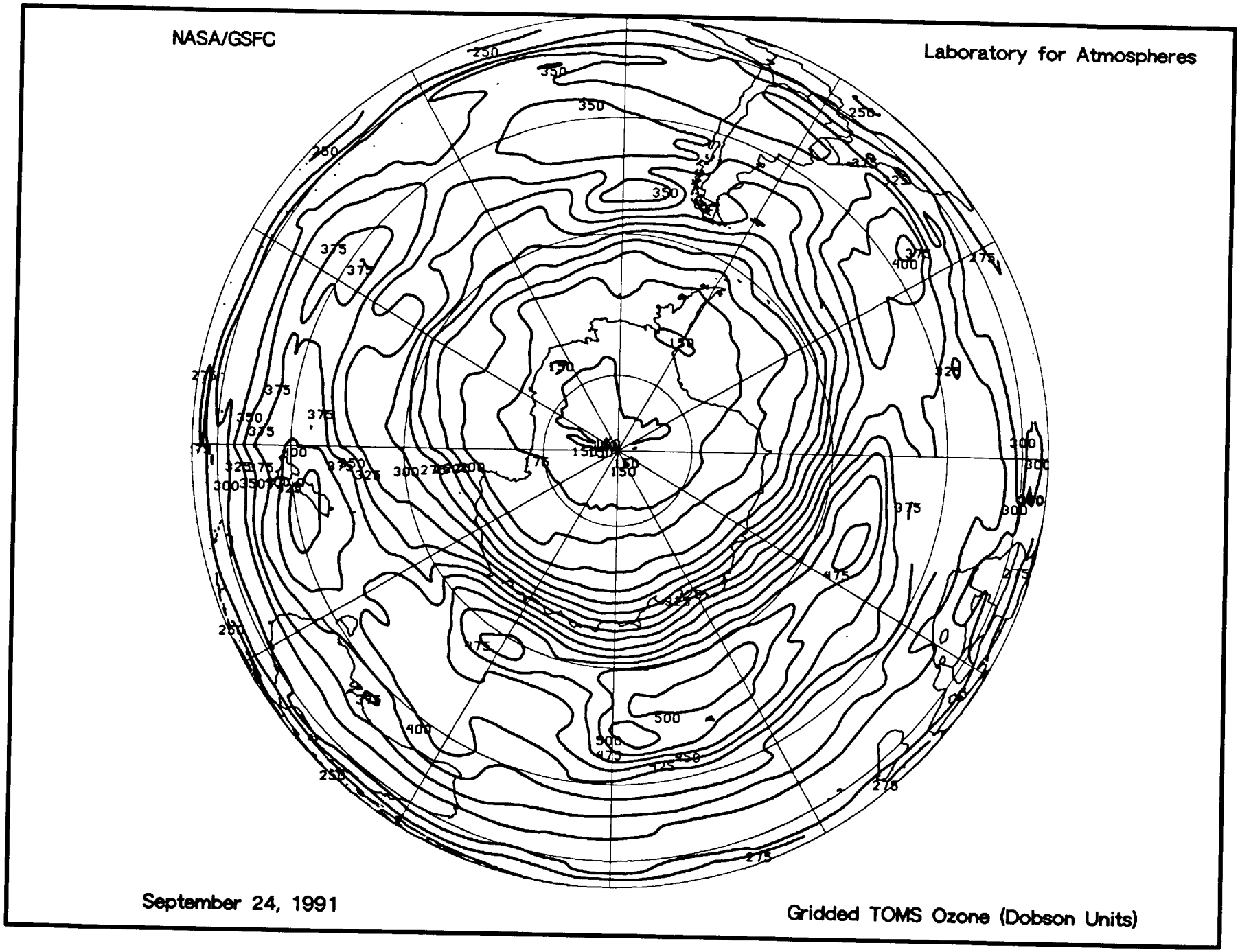
Laboratory for Atmospheres
September 23, 1991
Gridded TOMS Ozone (Dobson Units)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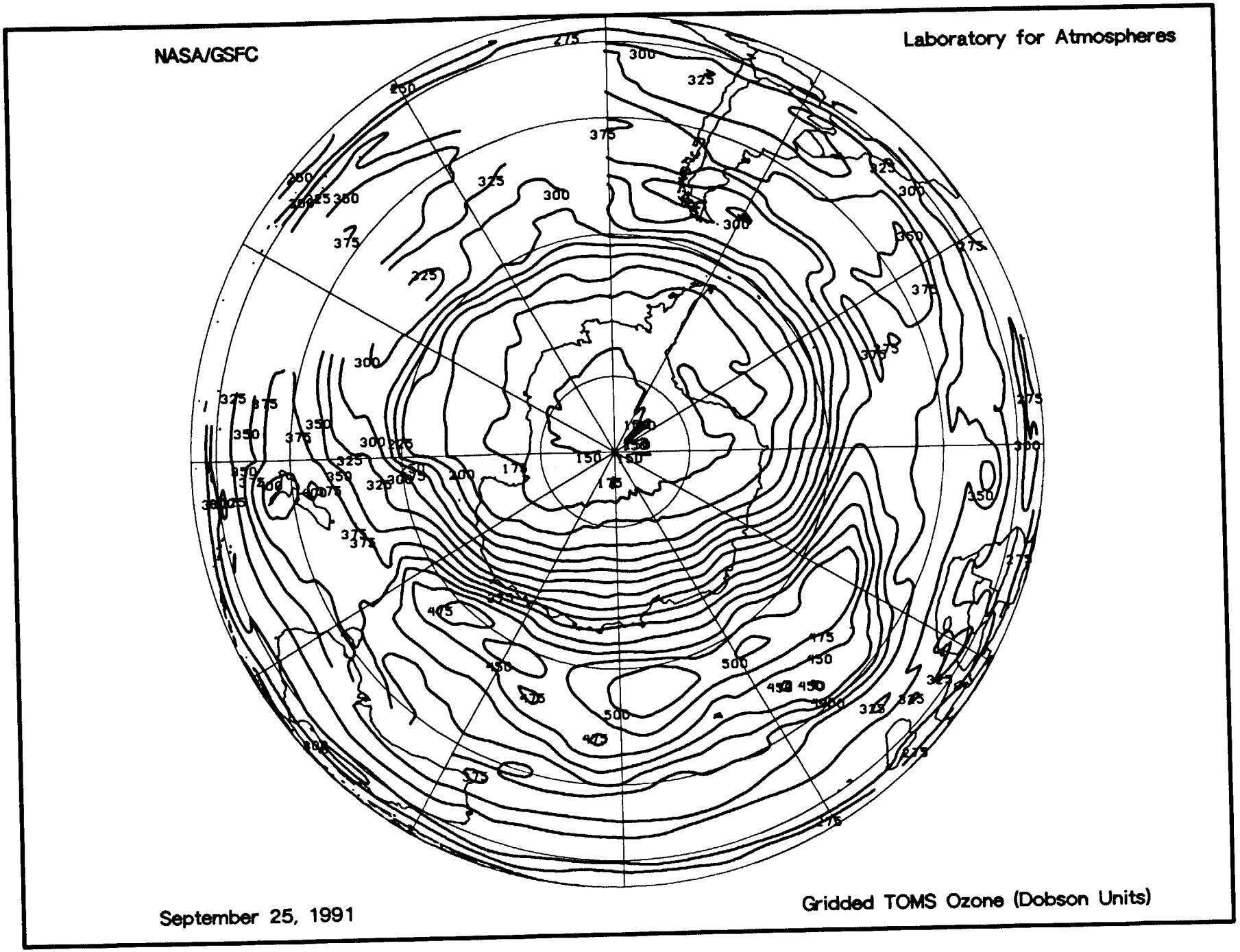
Laboratory for Atmospheres
September 24, 1991
Gridded TOMS Ozone (Dobson Units)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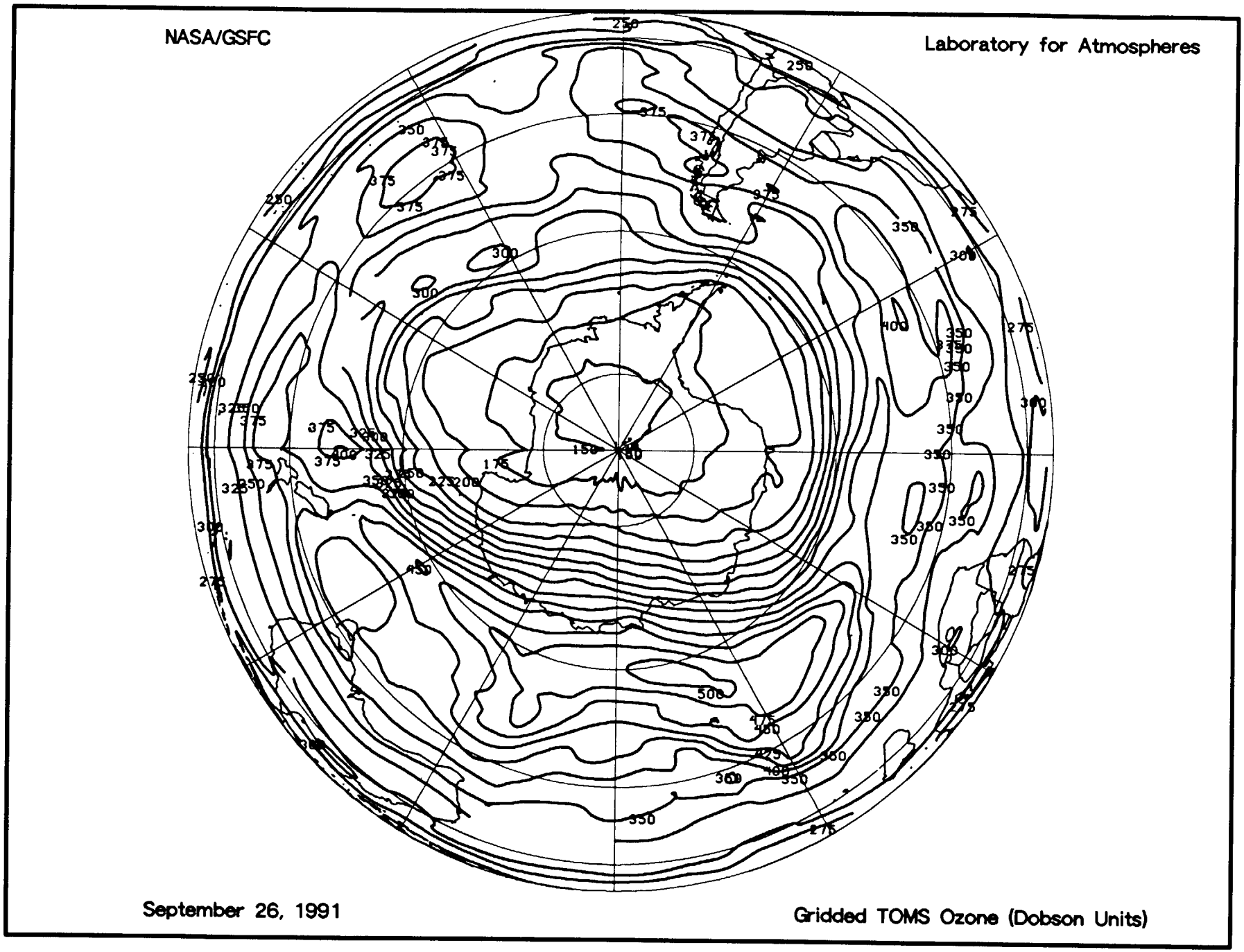
Laboratory for Atmospheres
September 25, 1991
Gridded TOMS Ozone (Dobson Units)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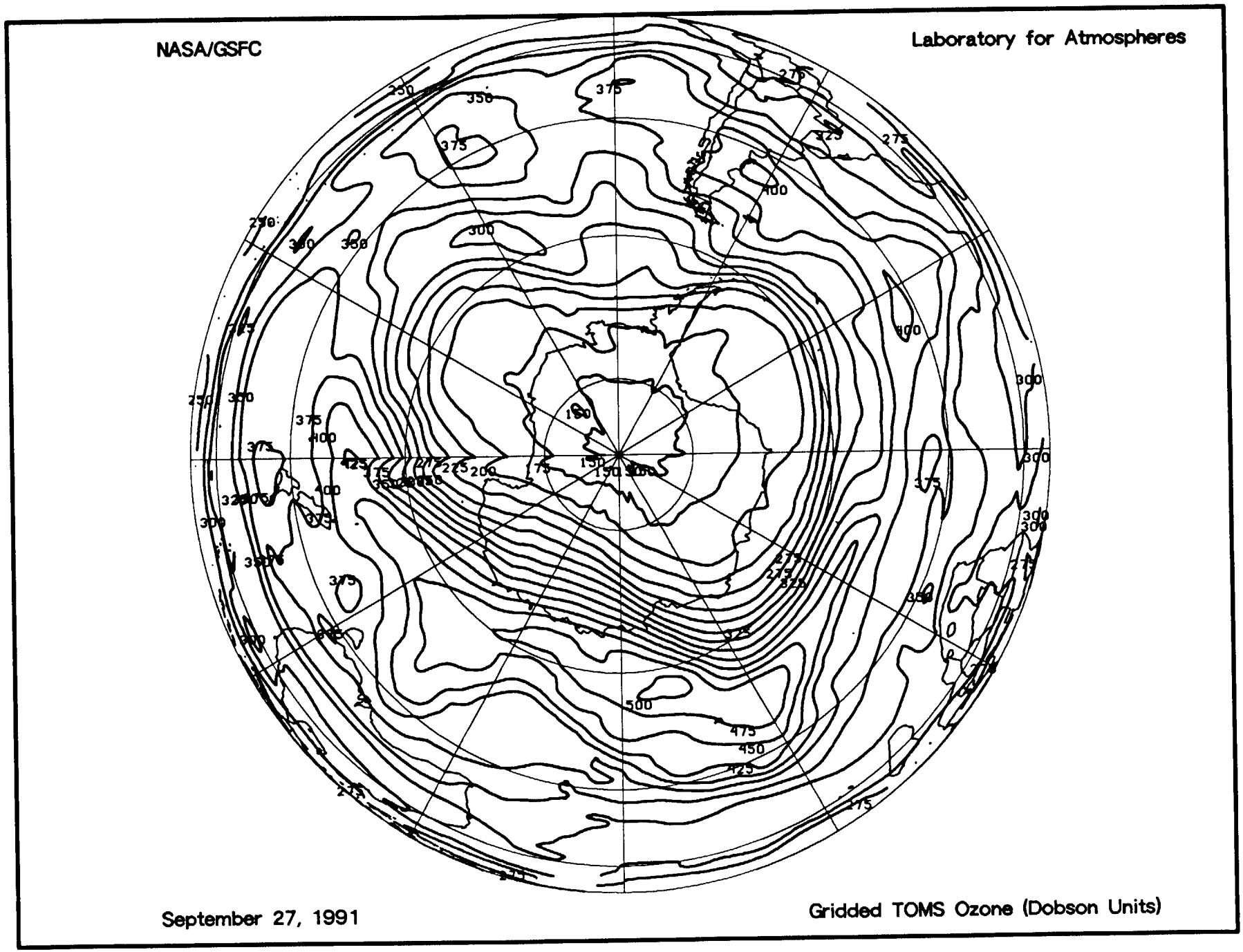
Laboratory for Atmospheres
September 26, 1991
Gridded TOMS Ozone (Dobson Units)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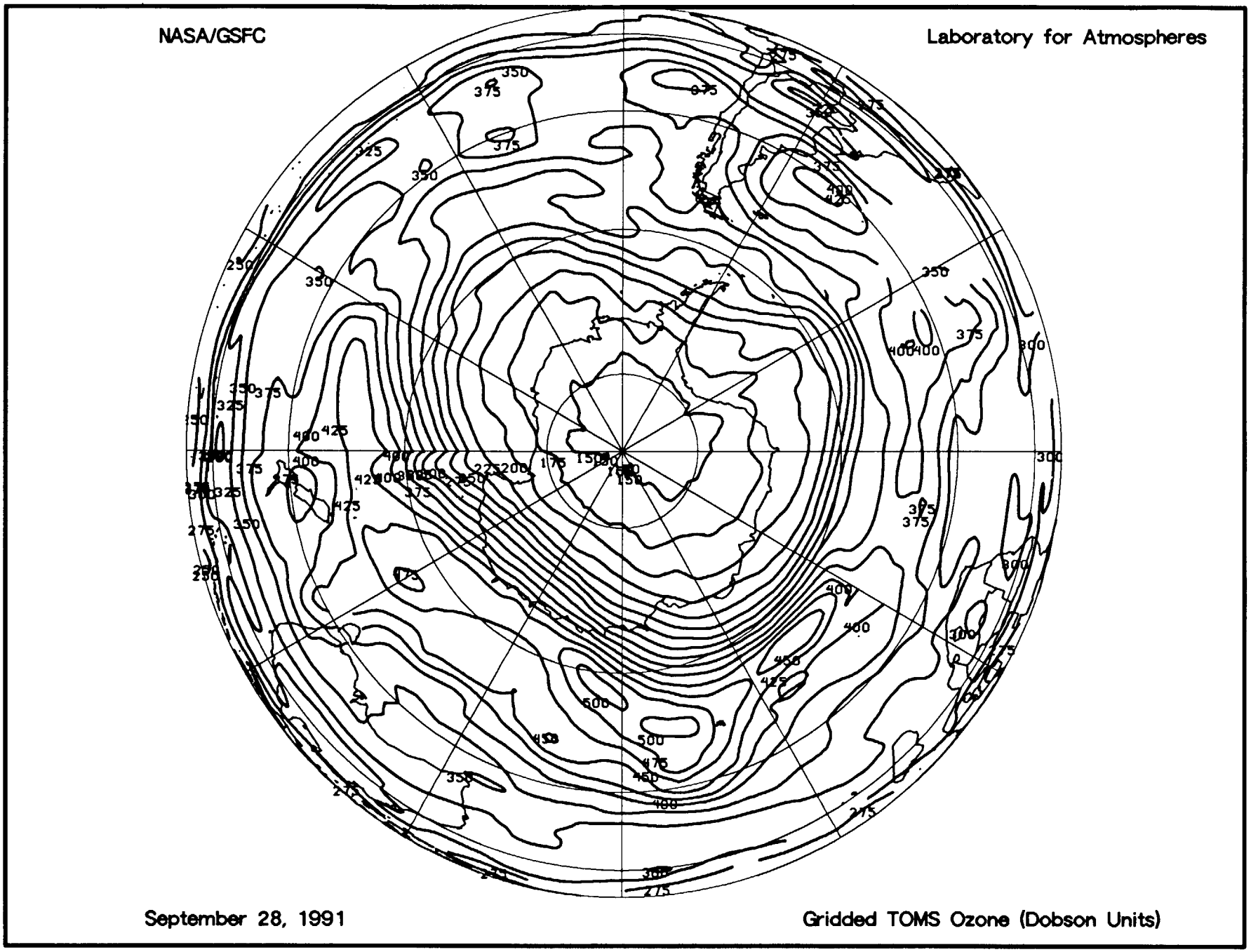
Laboratory for Atmospheres
September 27, 1991
Gridded TOMS Ozone (Dobson Units)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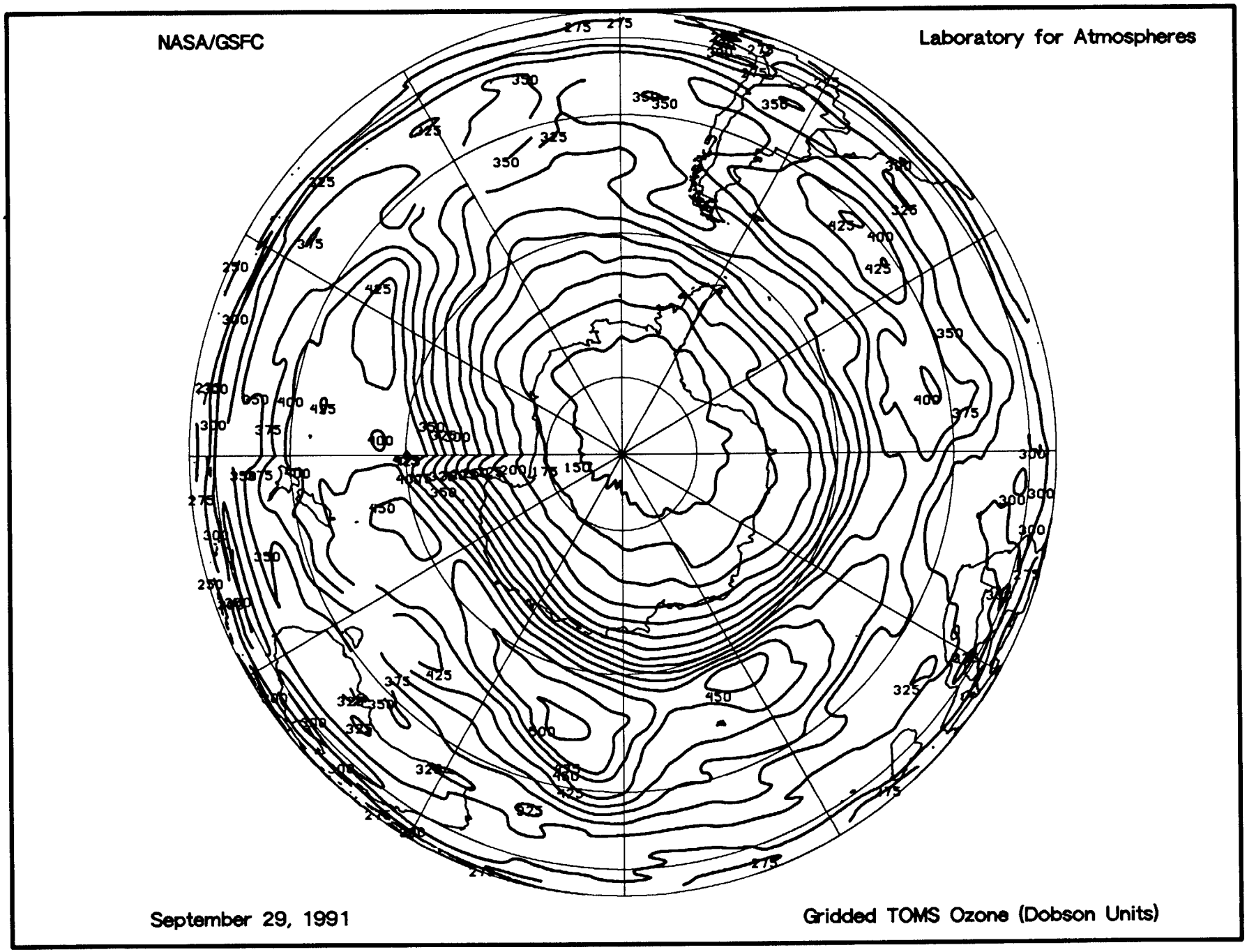
Laboratory for Atmospheres
September 28, 1991
Gridded TOMS Ozone (Dobson Units)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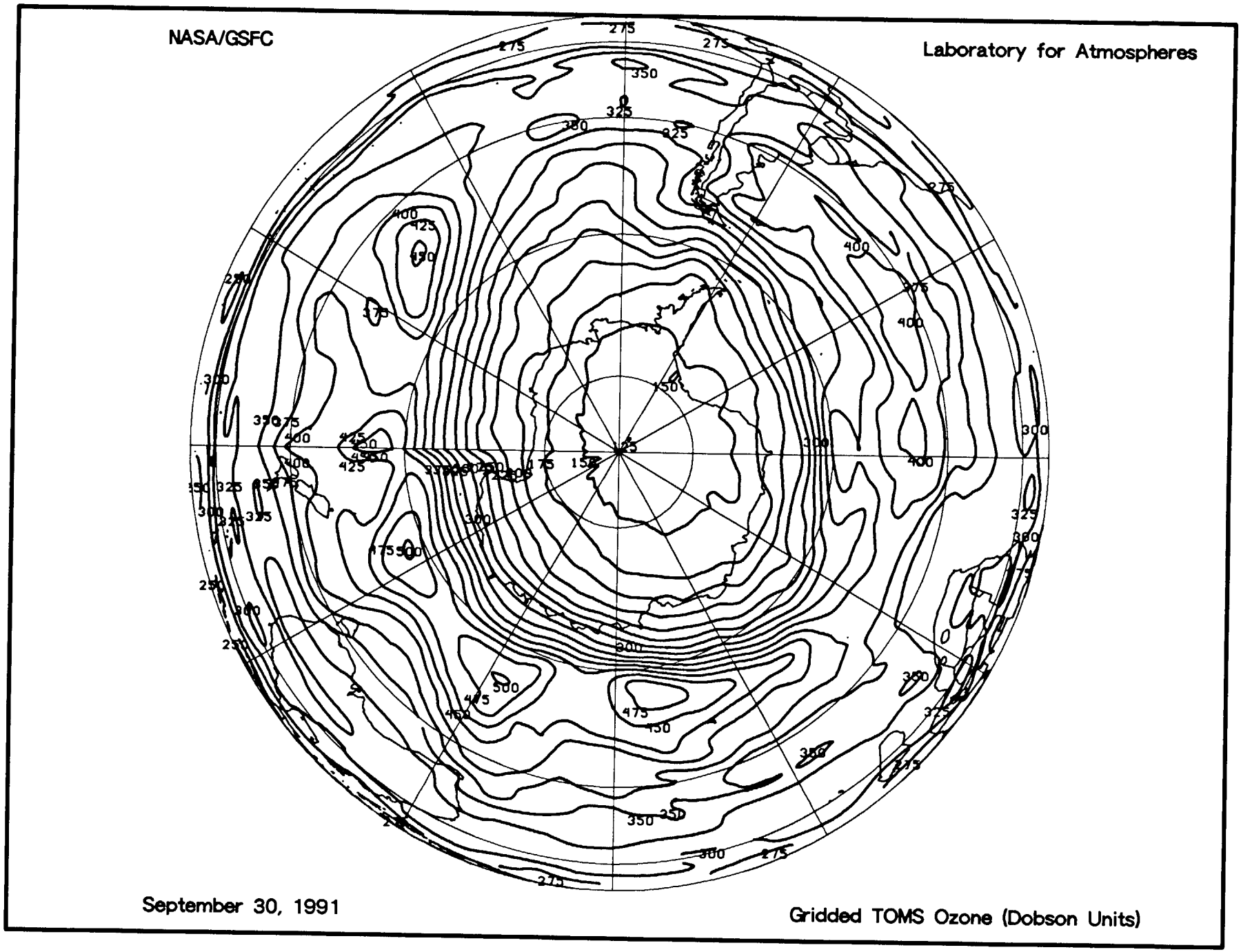
Laboratory for Atmospheres
September 29, 1991
Gridded TOMS Ozone (Dobson Units)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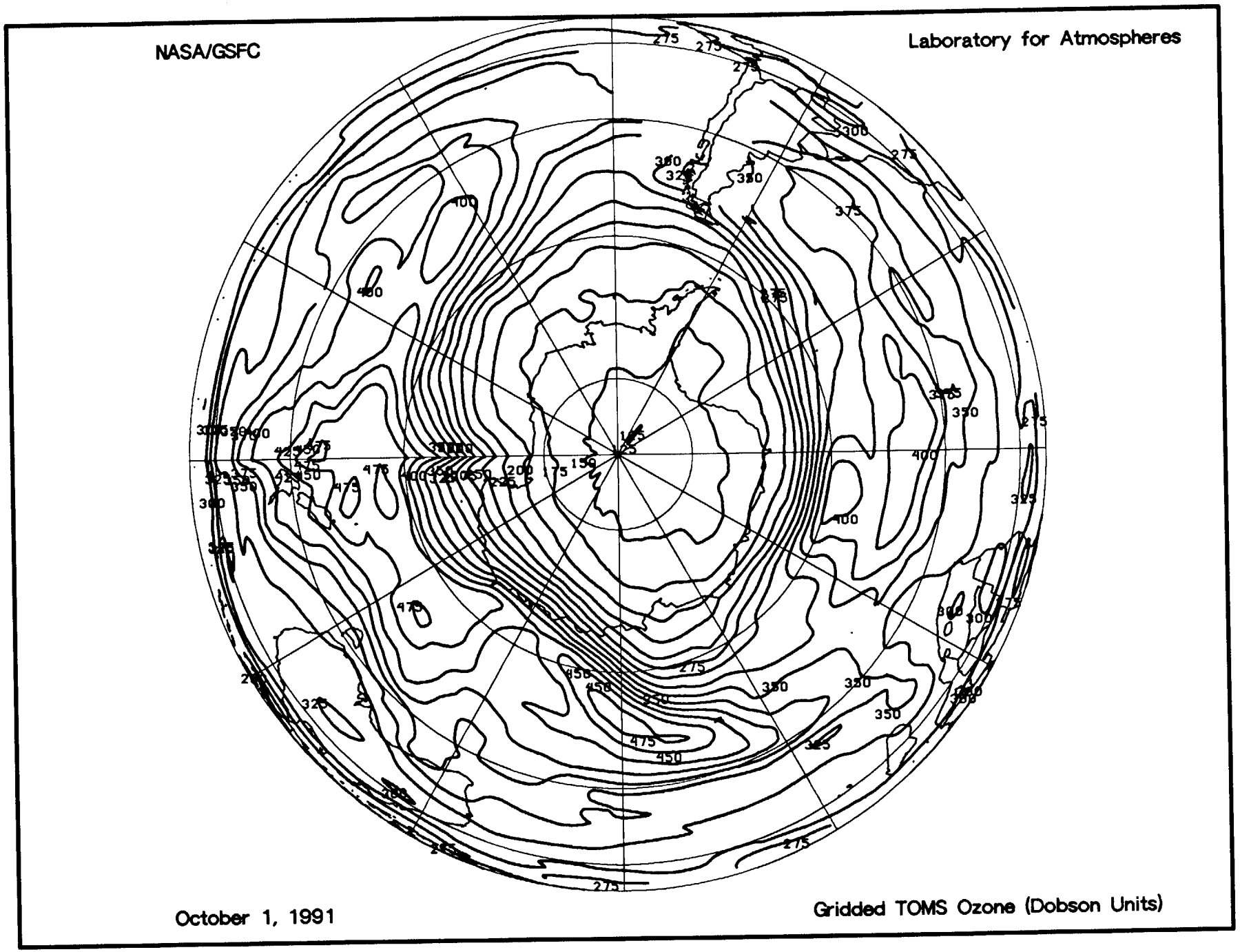
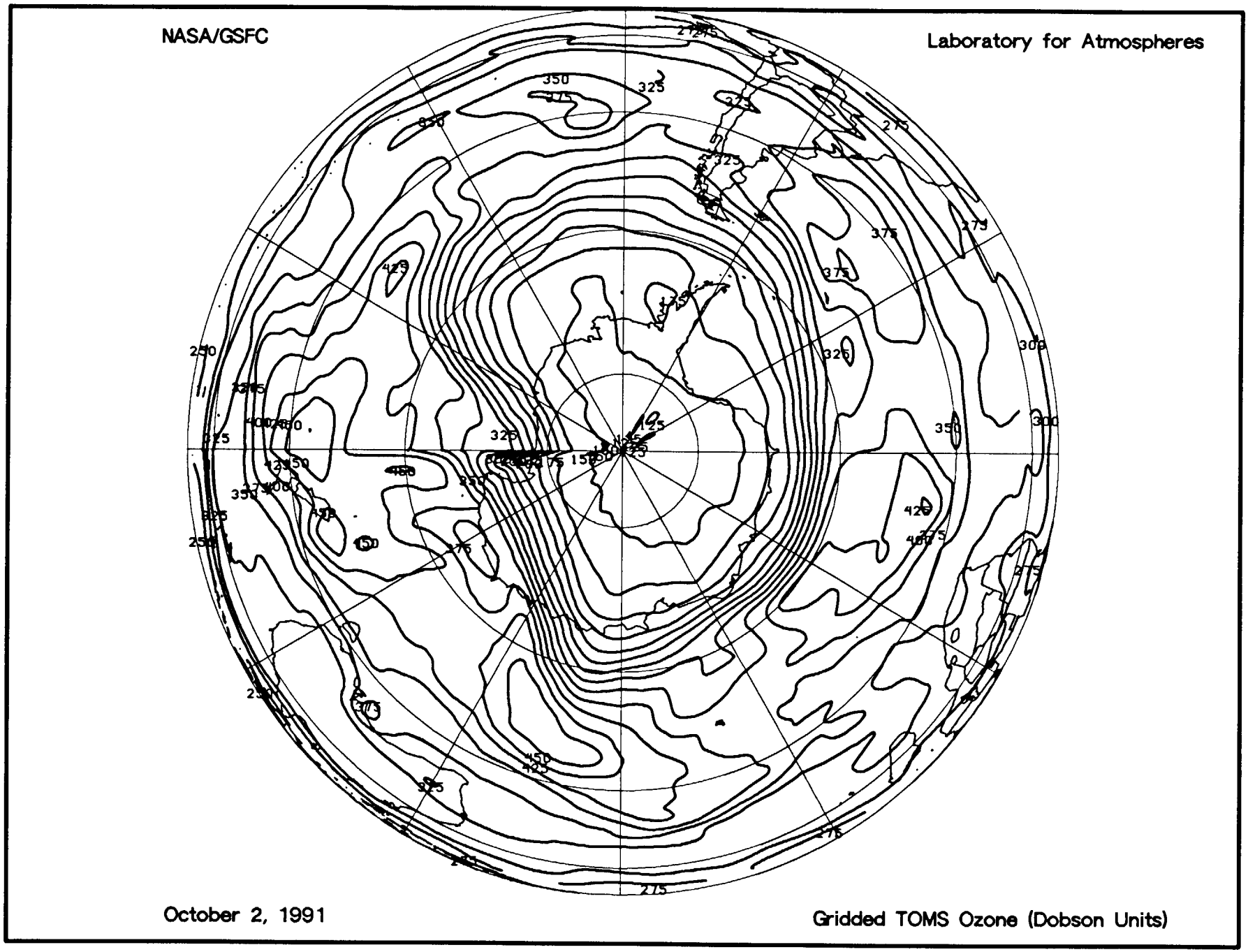
Laboratory for Atmospheres
September 30, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 1, 1991
Gridded TOMS Ozone (Dobson Units)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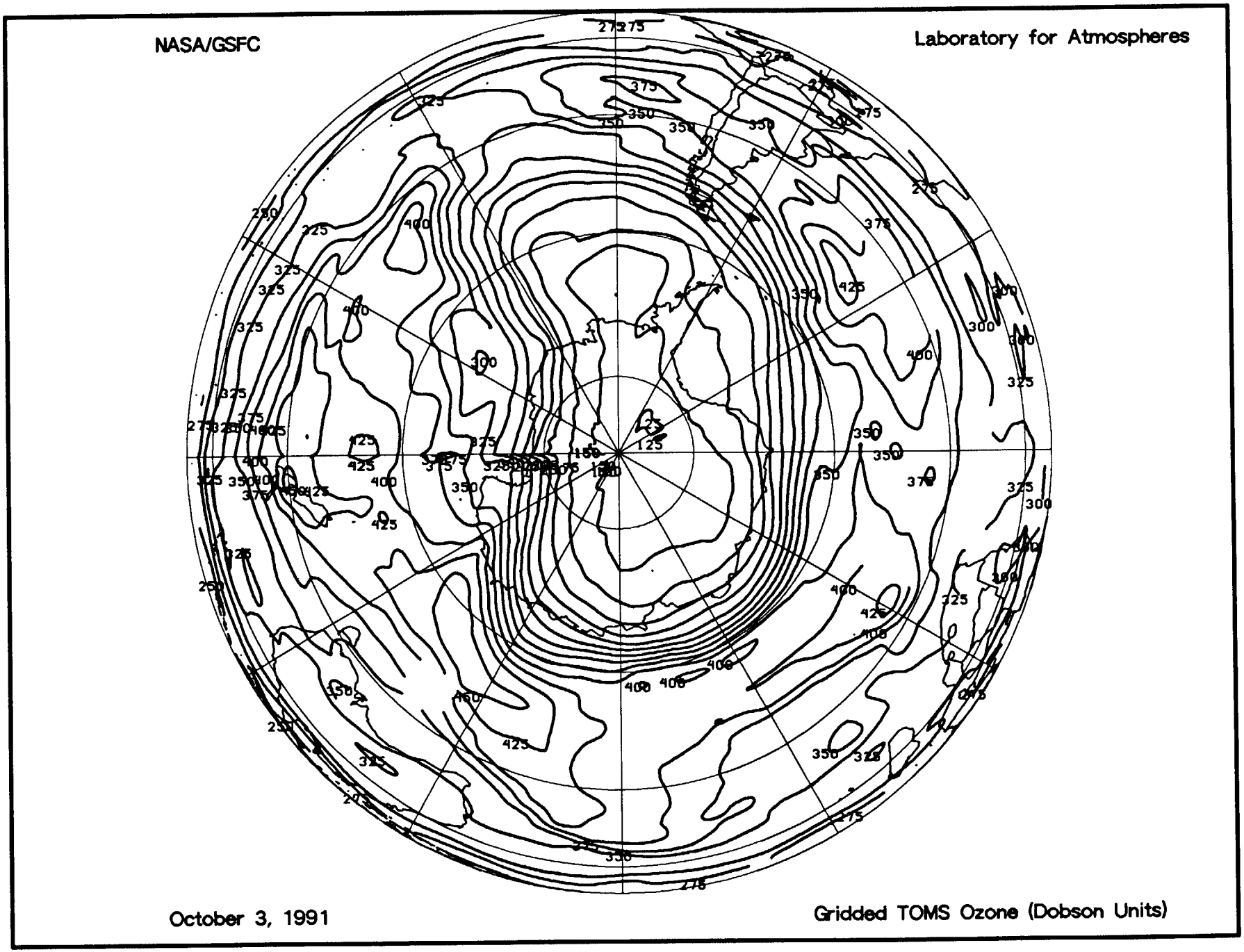
Laboratory for Atmospheres
October 2, 1991
Gridded TOMS Ozone (Dobson Units)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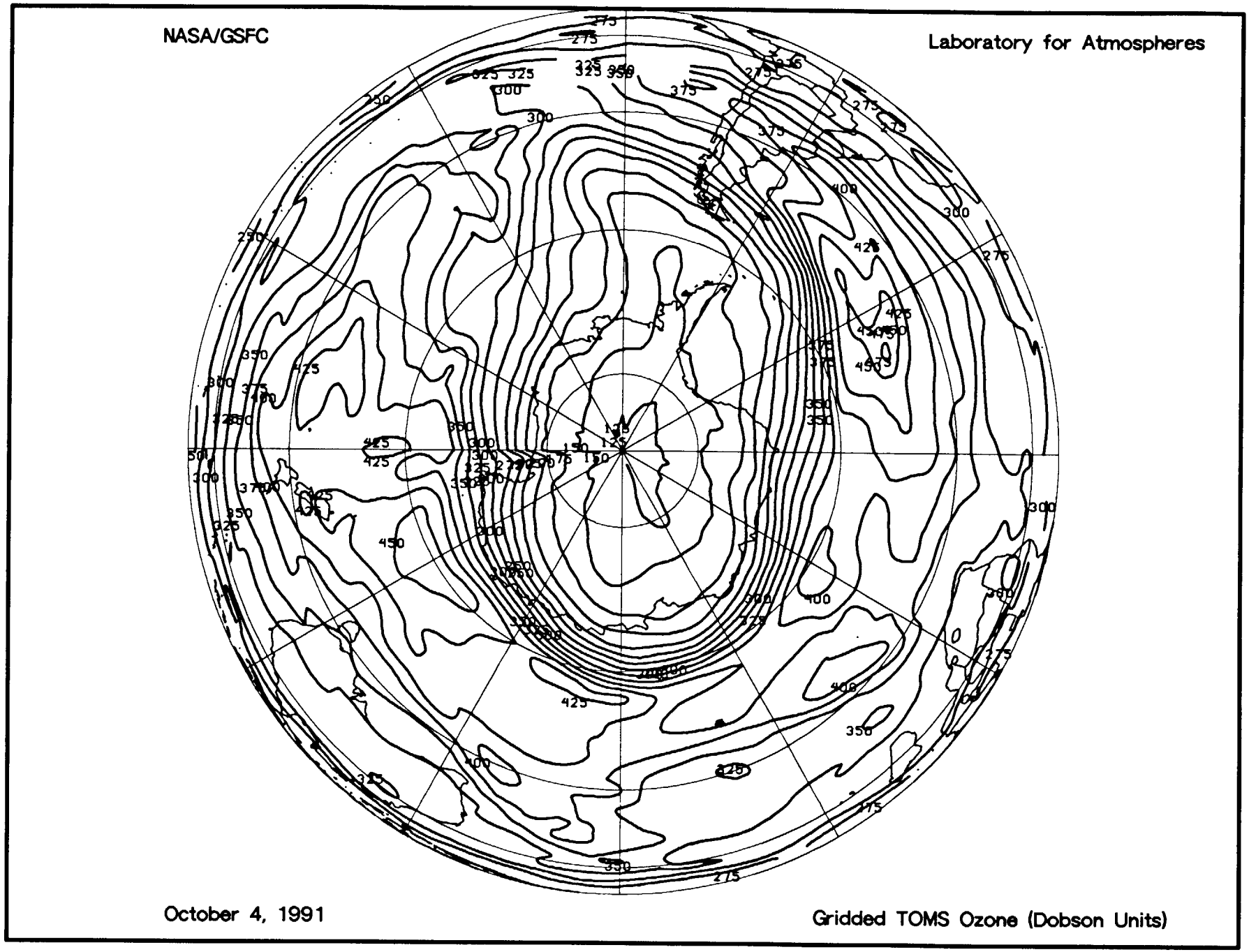
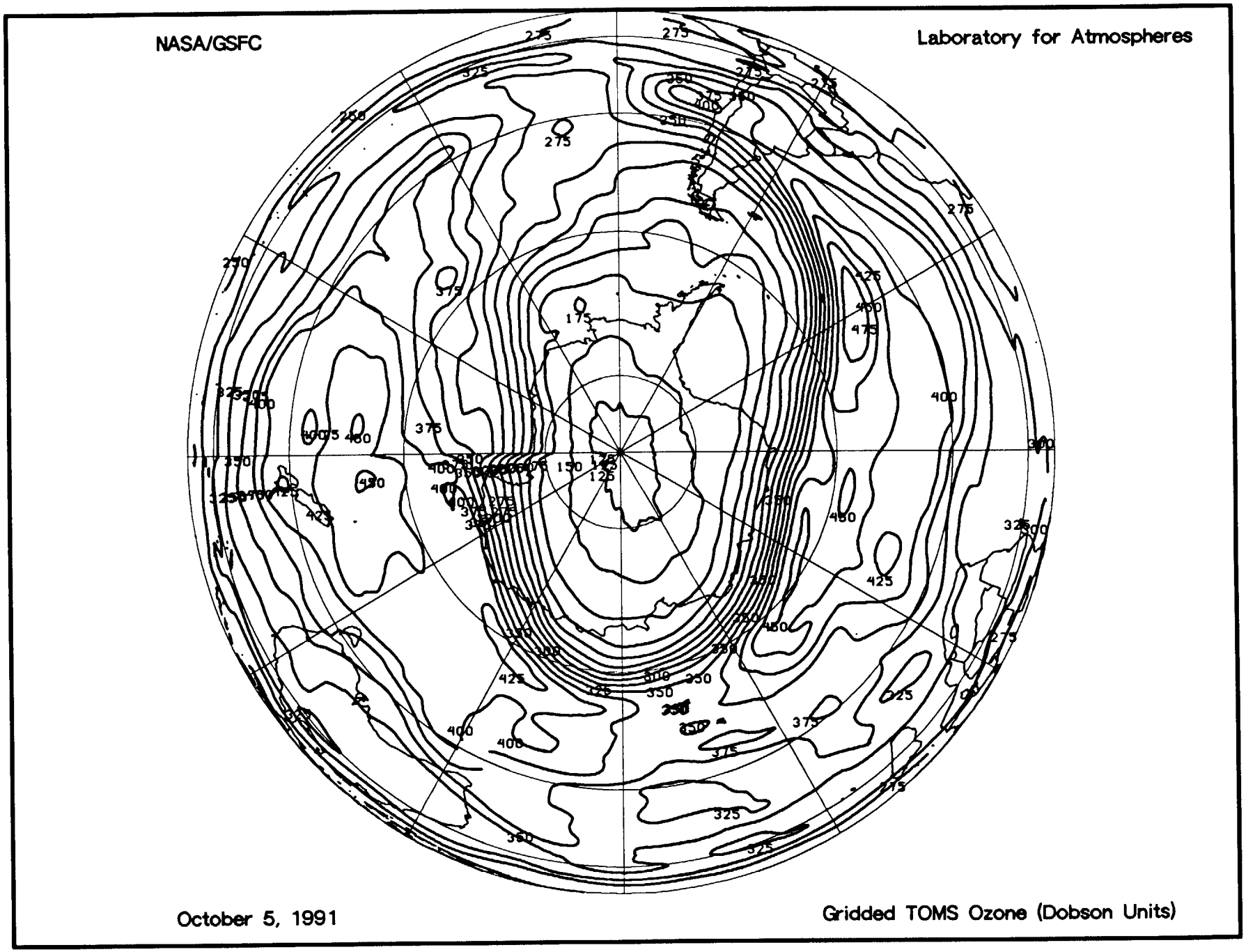
Laboratory for Atmospheres
October 3, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 4, 1991
Gridded TOMS Ozone (Dobson Units)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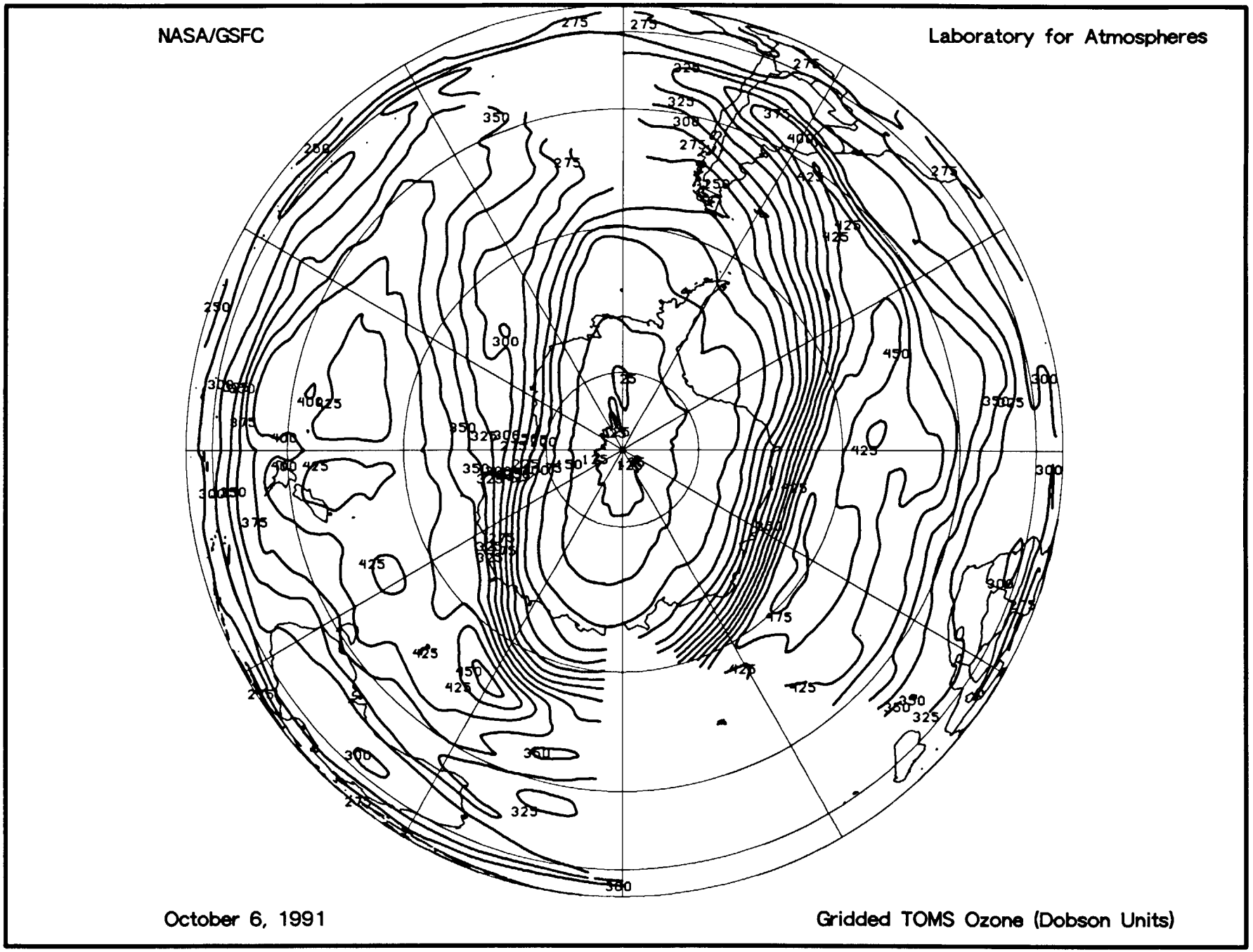
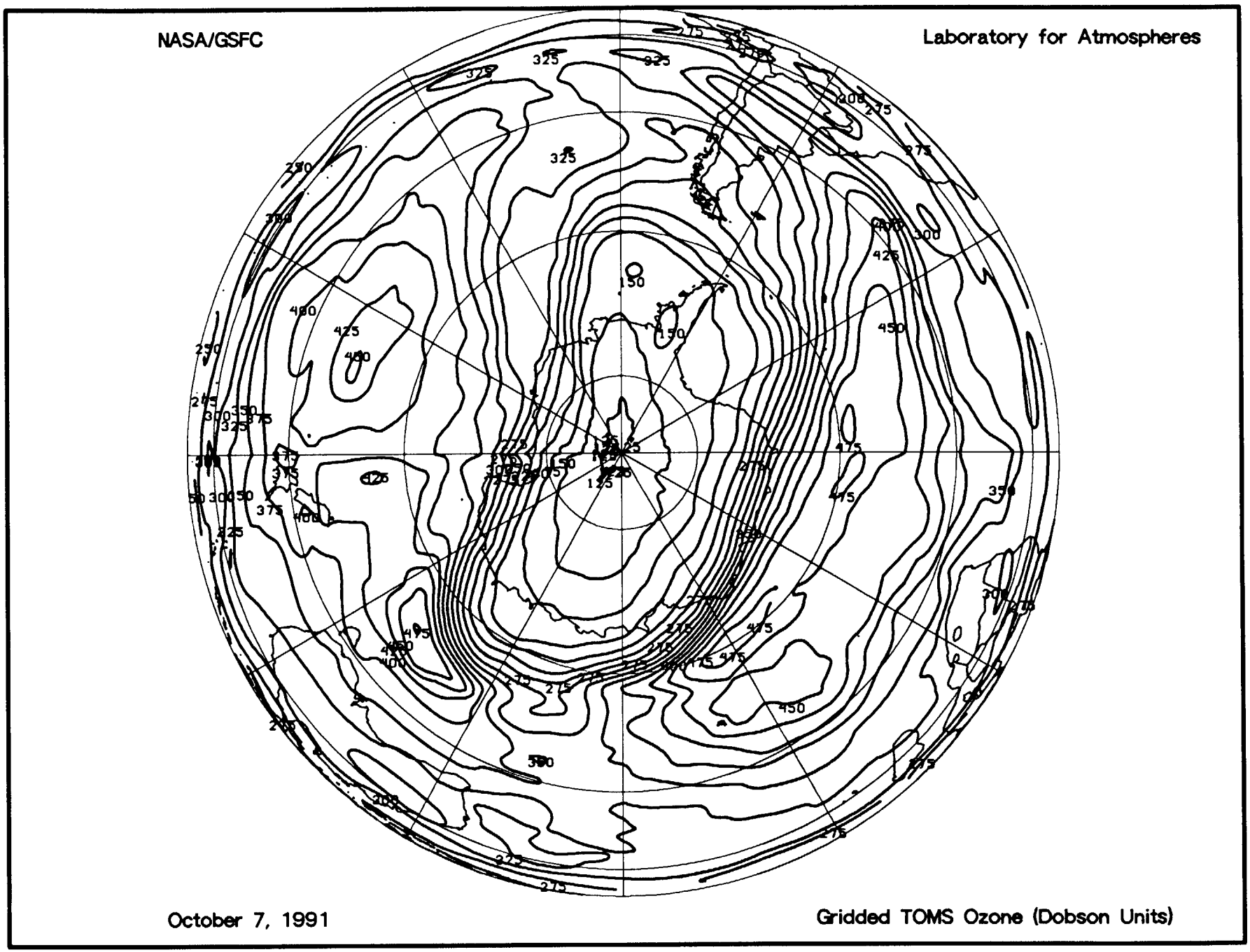
Laboratory for Atmospheres
October 5, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 6, 1991
Gridded TOMS Ozone (Dobson Units)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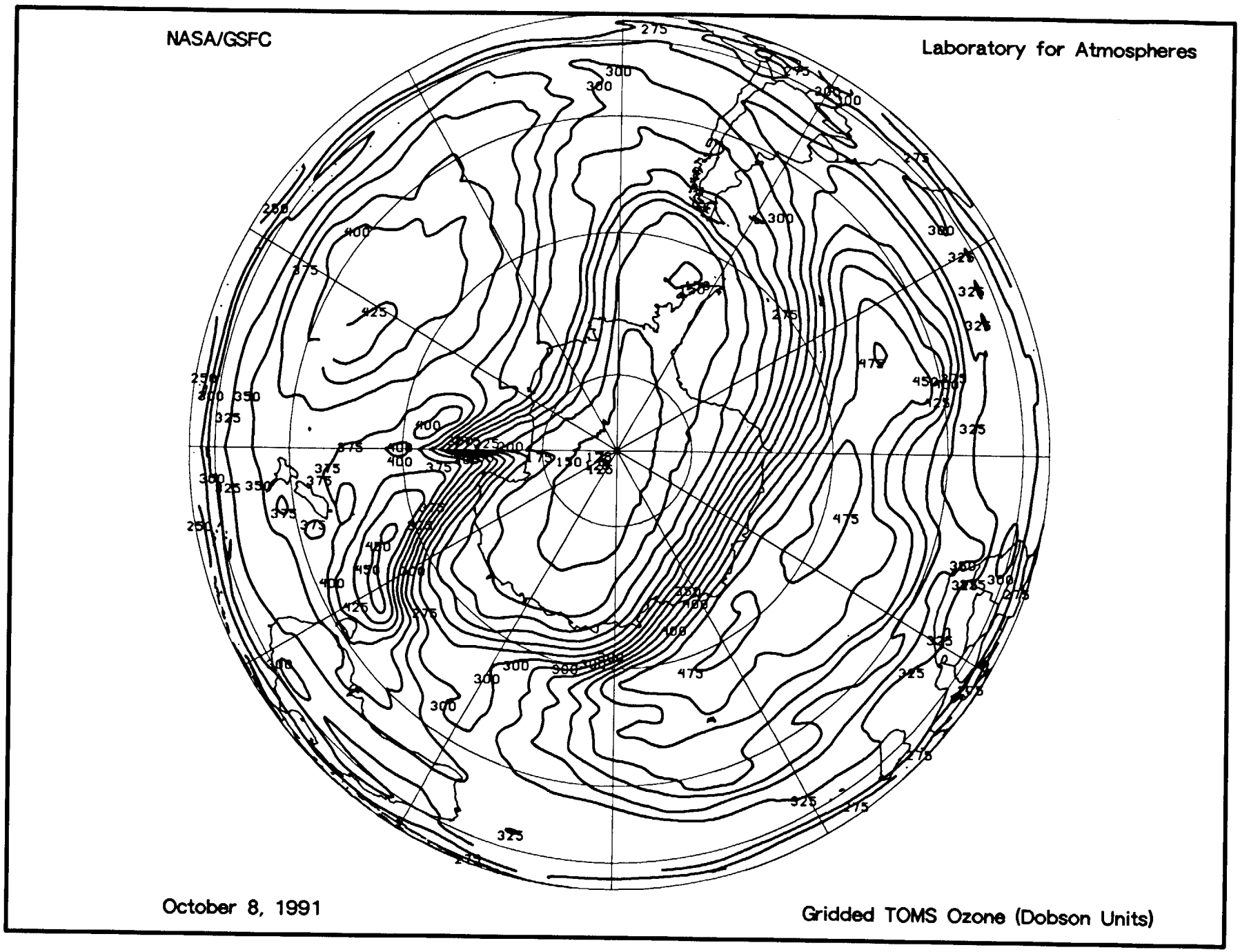
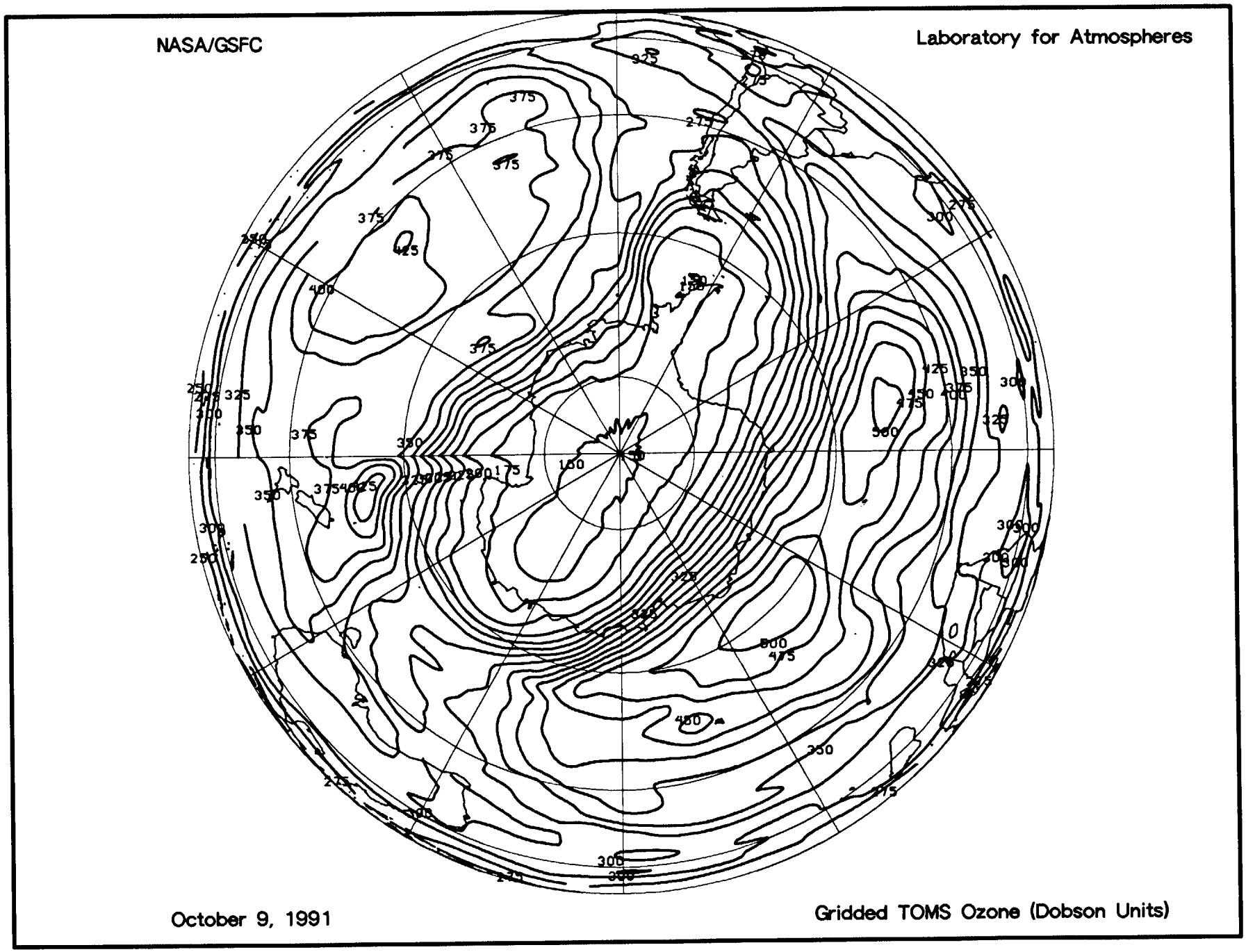
Laboratory for Atmospheres
October 7, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 8, 1991
Gridded TOMS Ozone (Dobson Units)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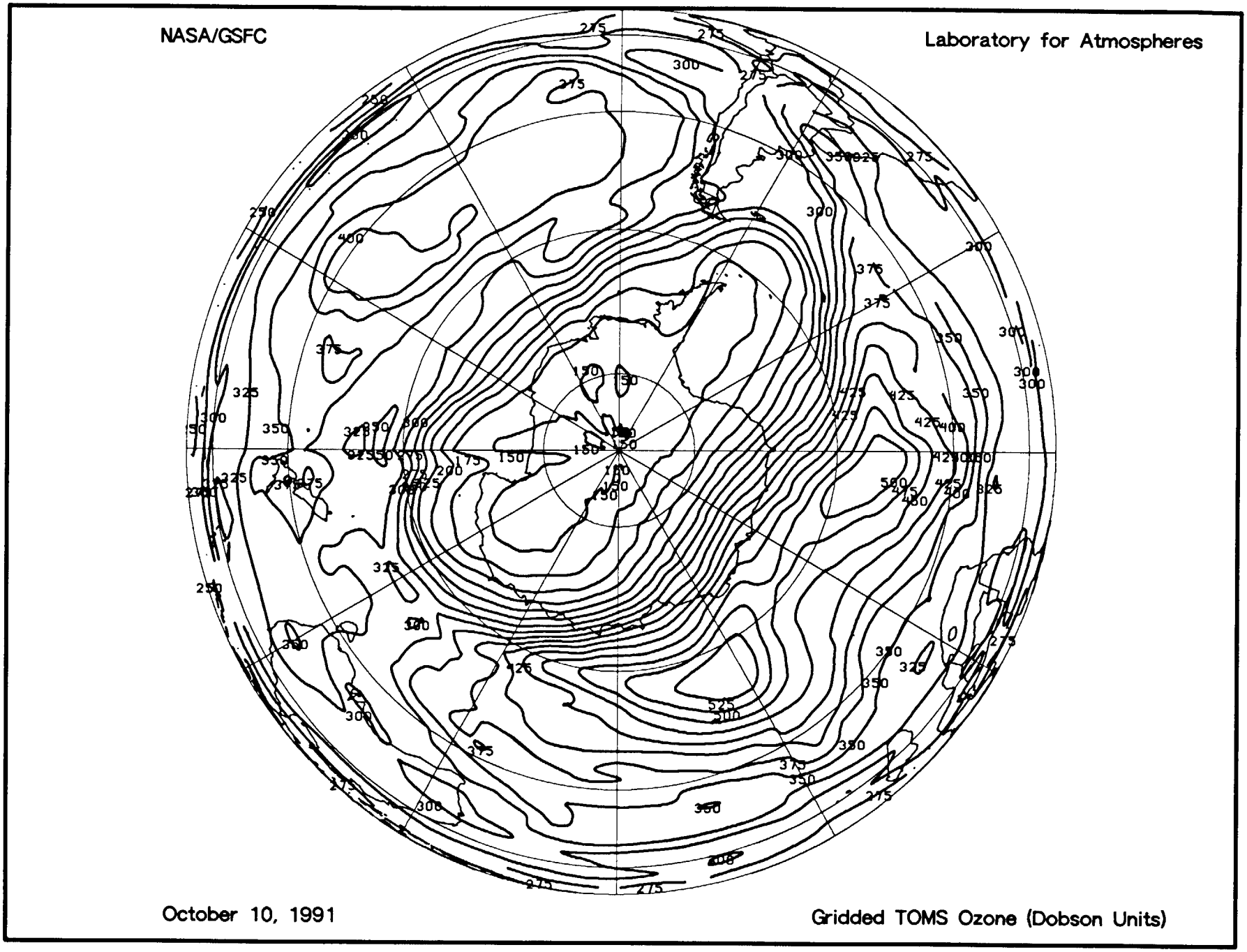
Laboratory for Atmospheres
October 9, 1991
Gridded TOMS Ozone (Dobson Units)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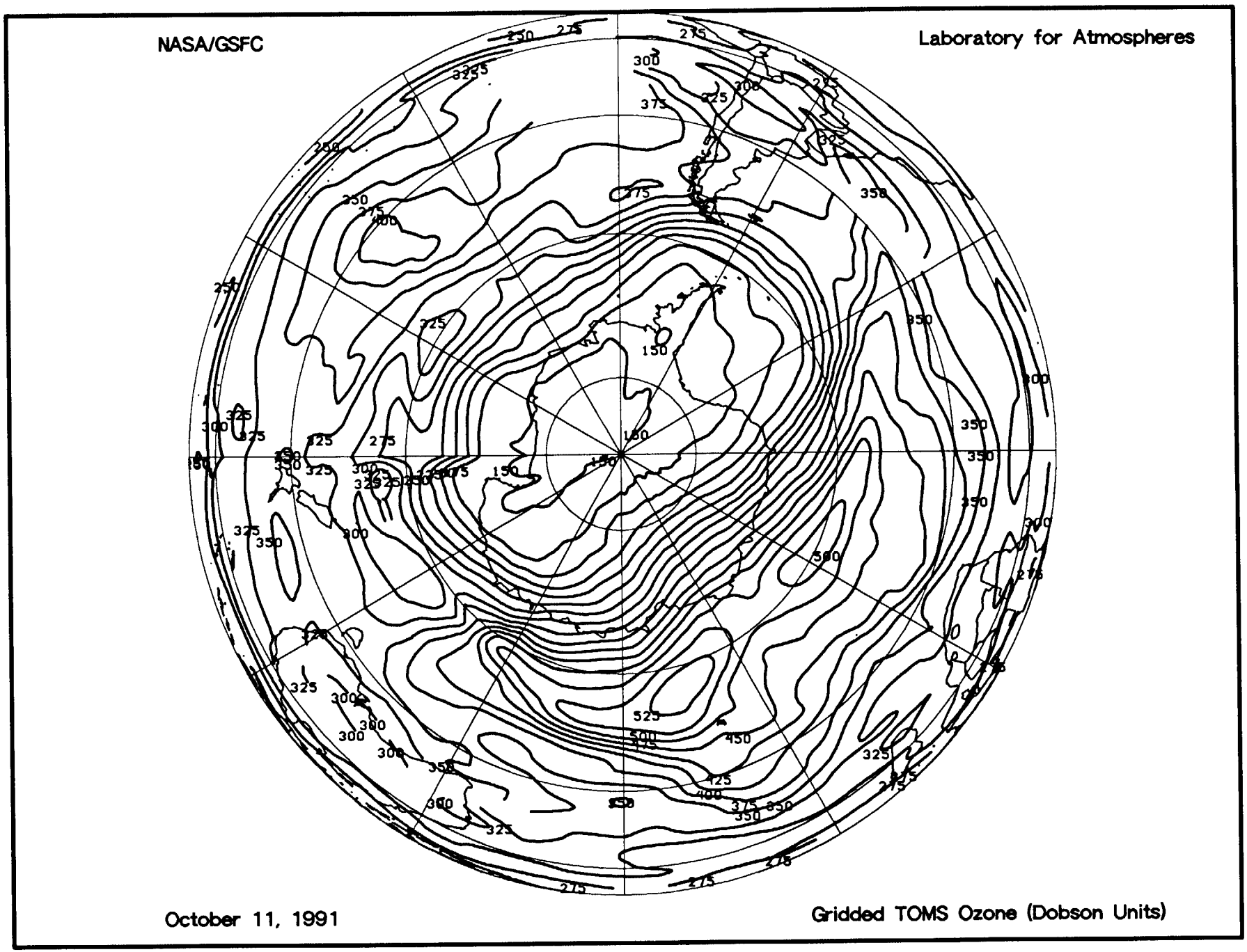
Laboratory for Atmospheres
October 10, 1991
Gridded TOMS Ozone (Dobson Units)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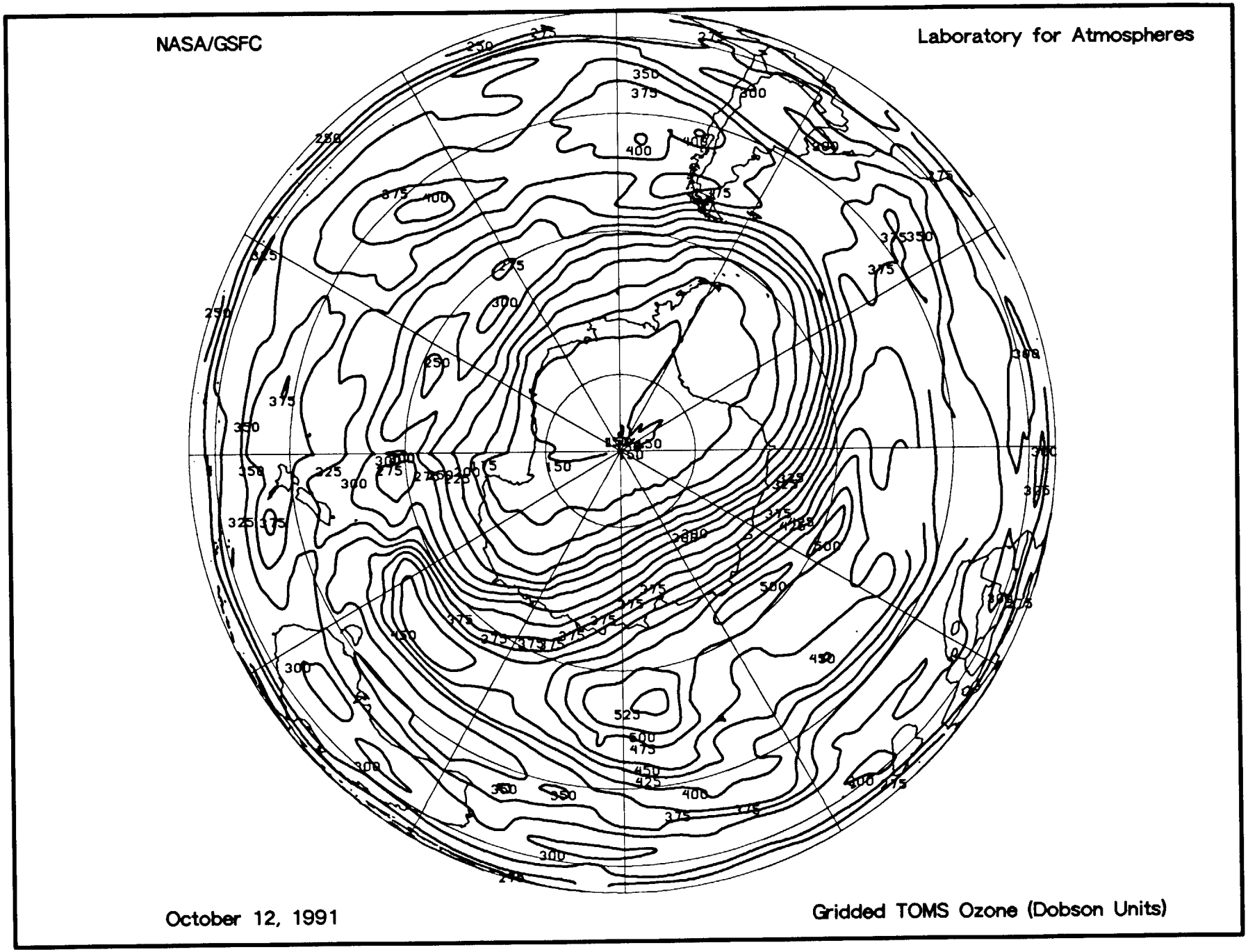
Laboratory for Atmospheres
October 11, 1991
Gridded TOMS Ozone (Dobson Units)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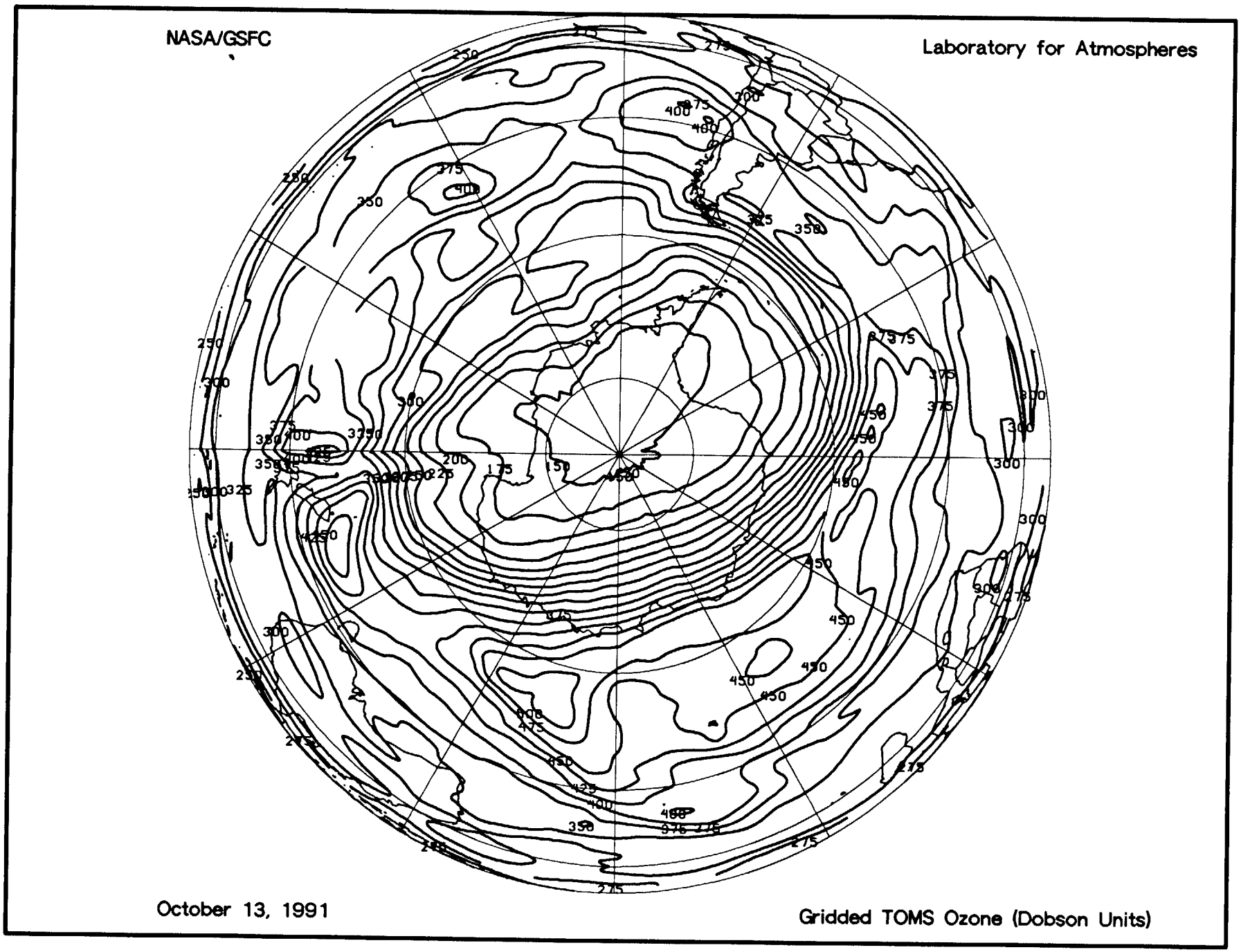
Laboratory for Atmospheres
October 12, 1991
Gridded TOMS Ozone (Dobson Units)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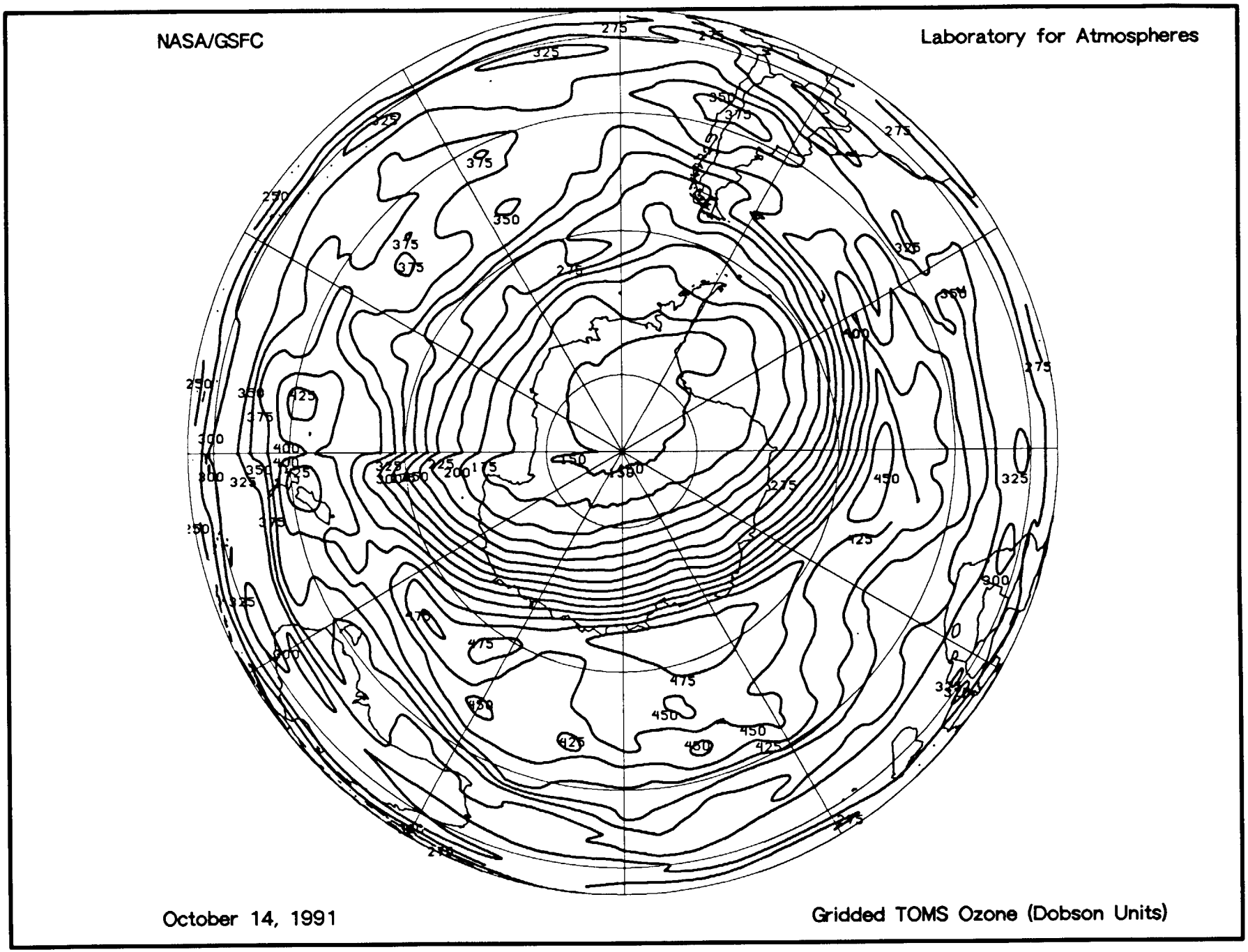
Laboratory for Atmospheres
October 13, 1991
Gridded TOMS Ozone (Dobson Units)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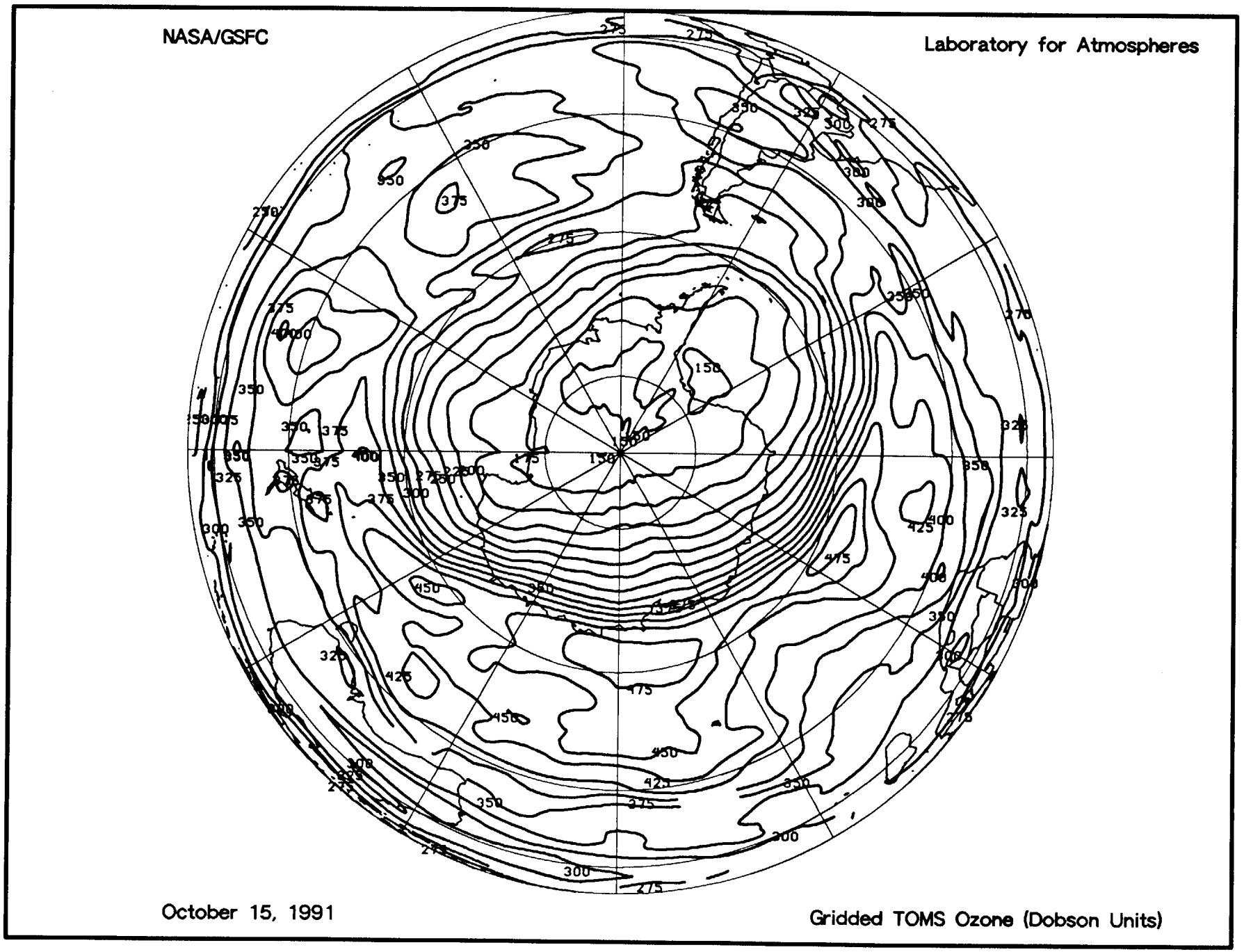
Laboratory for Atmospheres
October 14, 1991
Gridded TOMS Ozone (Dobson Units)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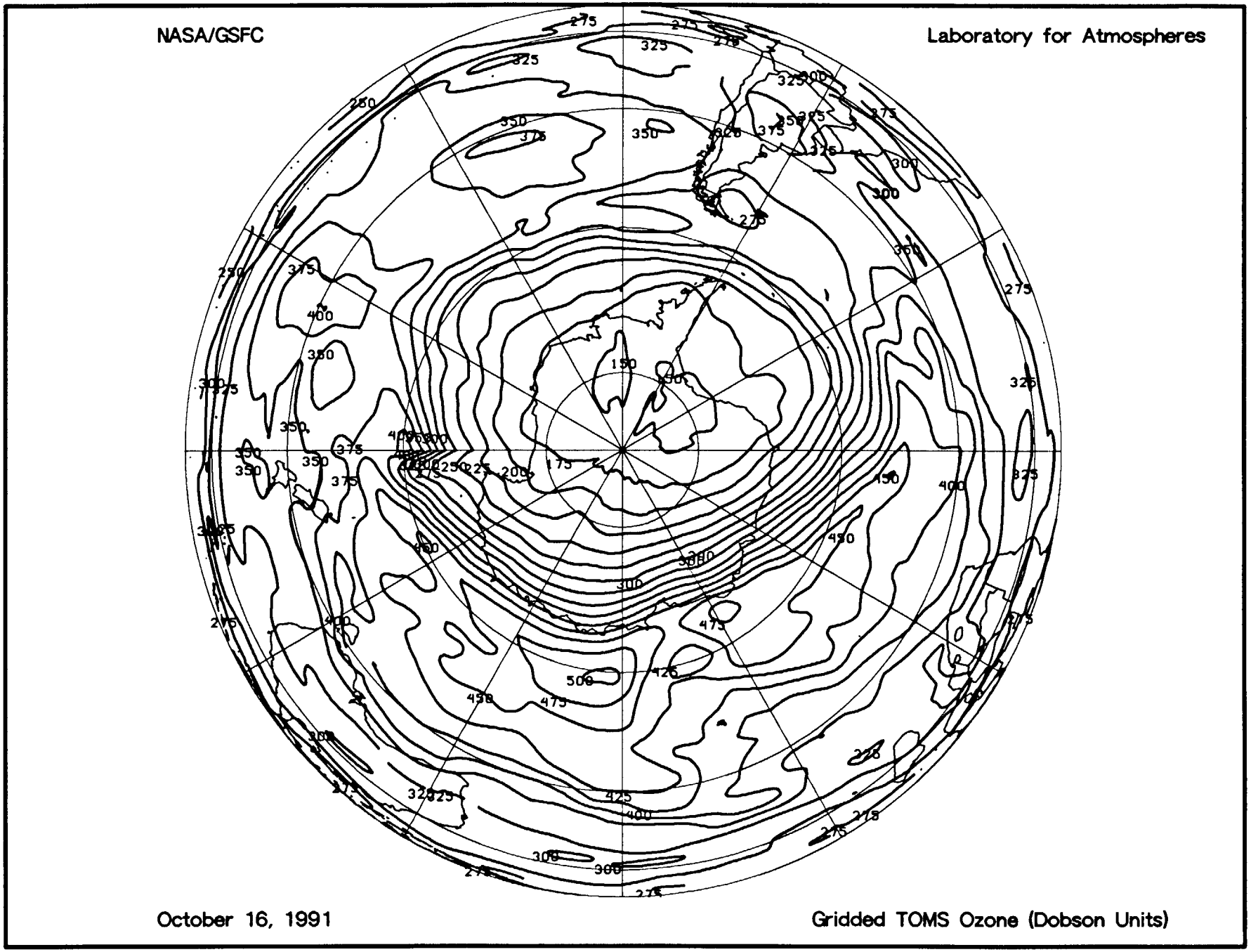
Laboratory for Atmospheres
October 15, 1991
Gridded TOMS Ozone (Dobson Units)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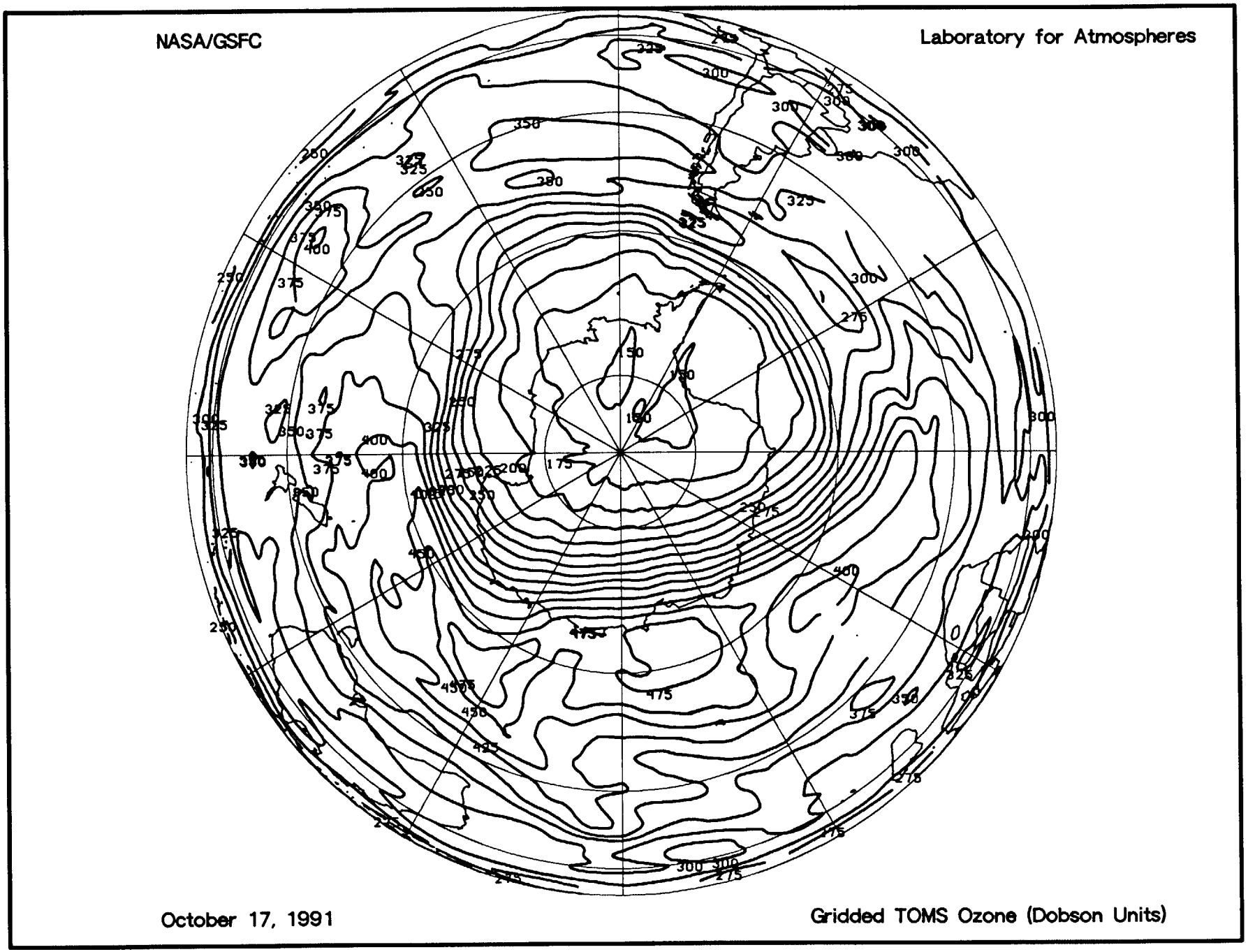
Laboratory for Atmospheres
October 16, 1991
Gridded TOMS Ozone (Dobson Units)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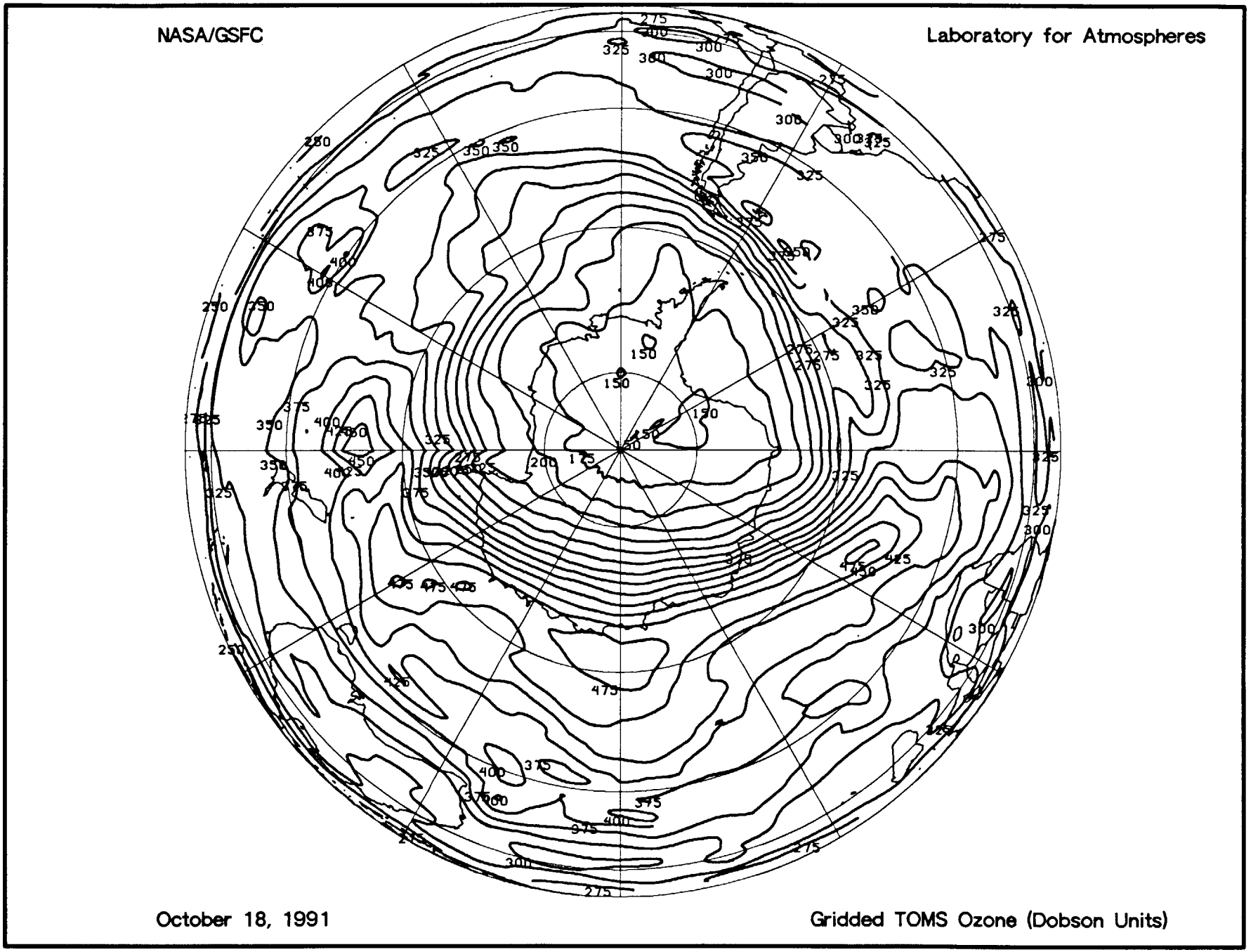
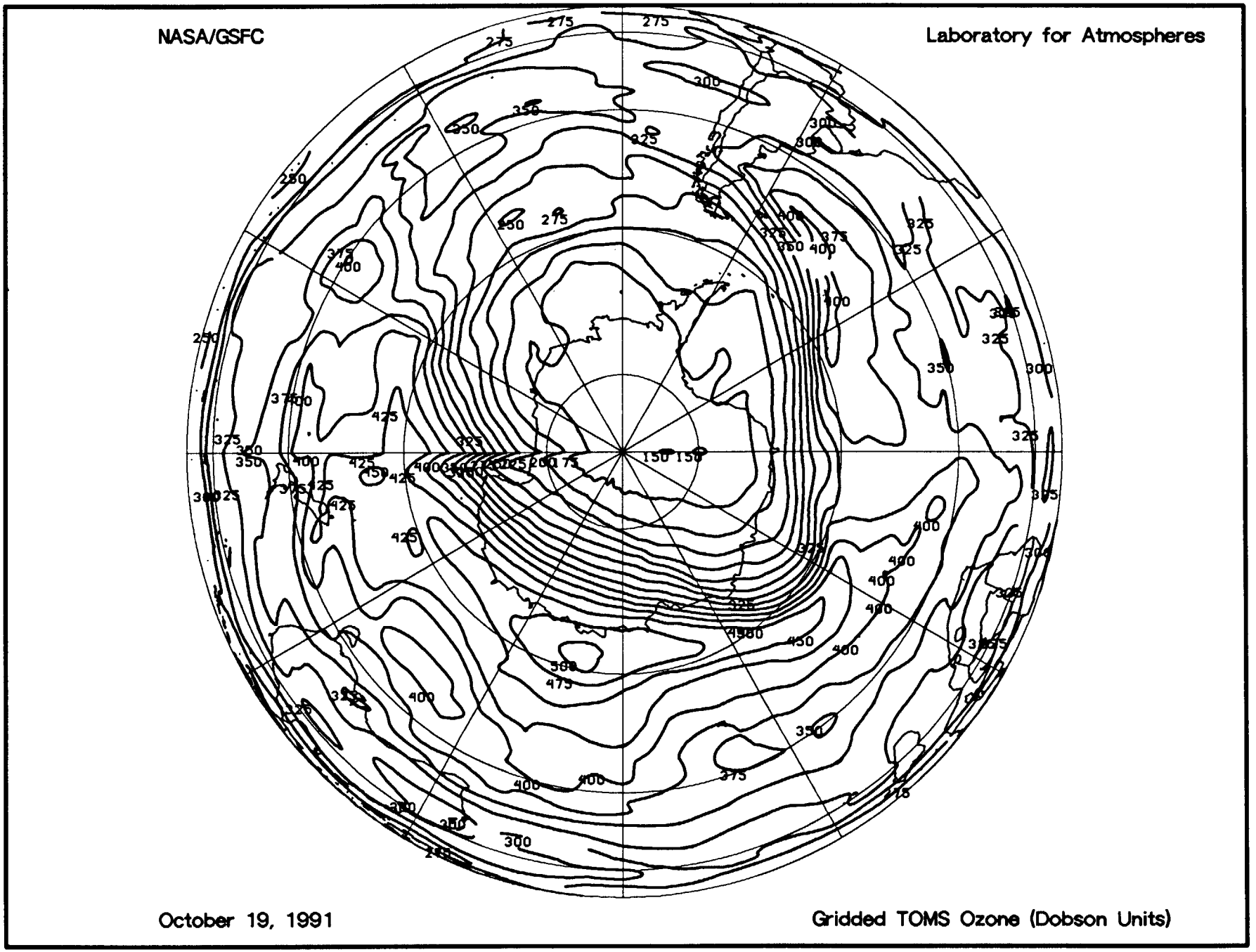
Laboratory for Atmospheres
October 17, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 18, 1991
Gridded TOMS Ozone (Dobson Units)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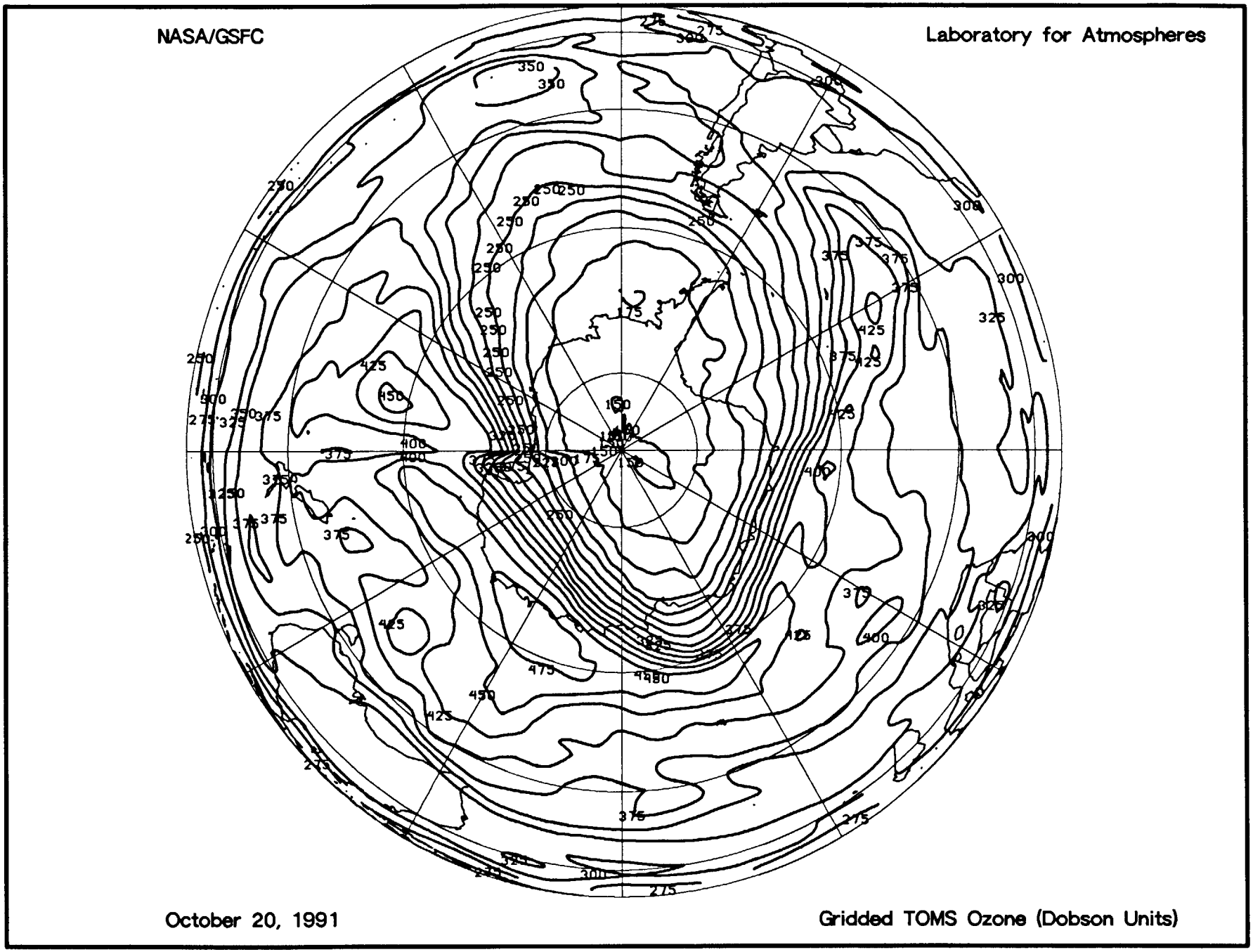
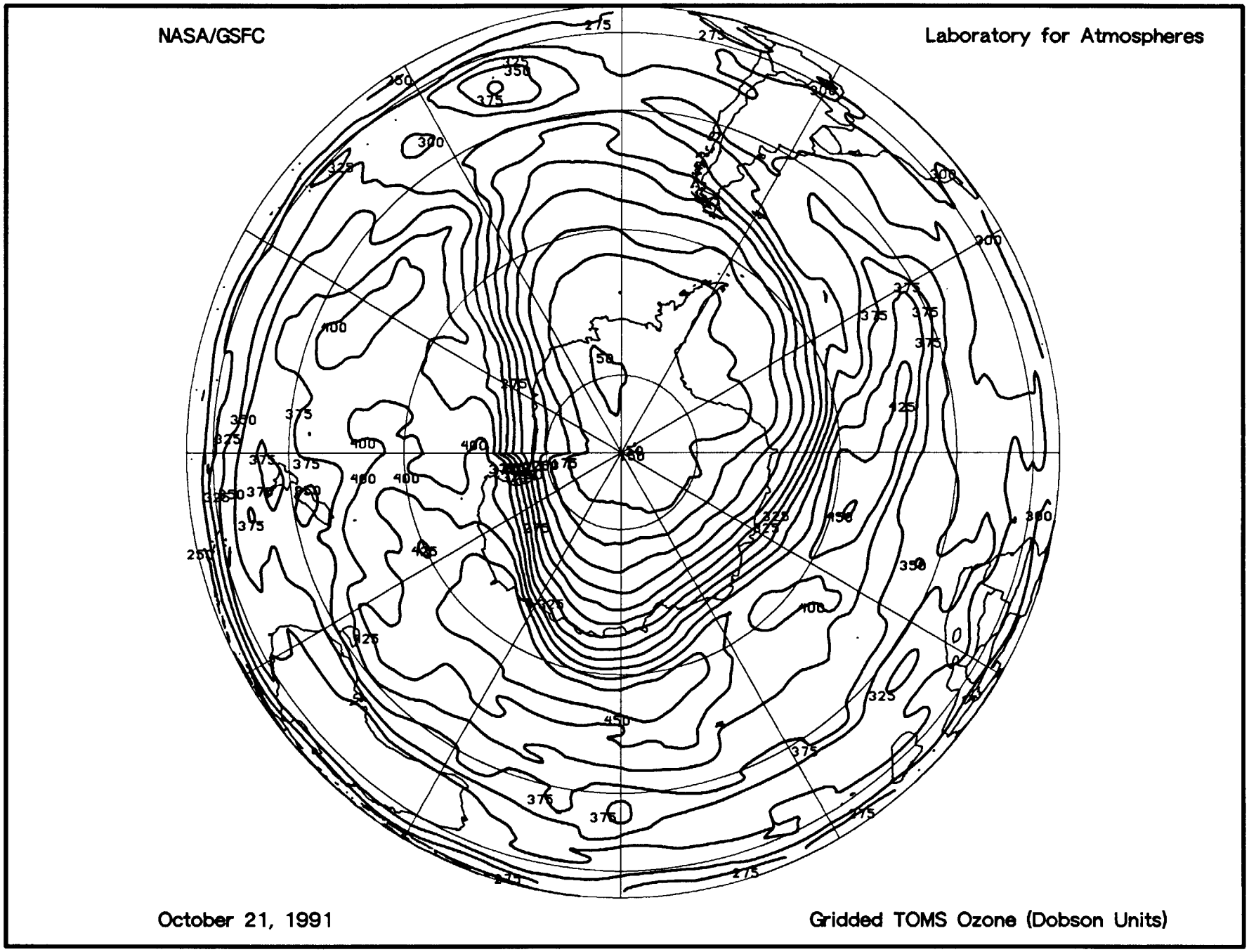
Laboratory for Atmospheres
October 19, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 20, 1991
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 21, 1991
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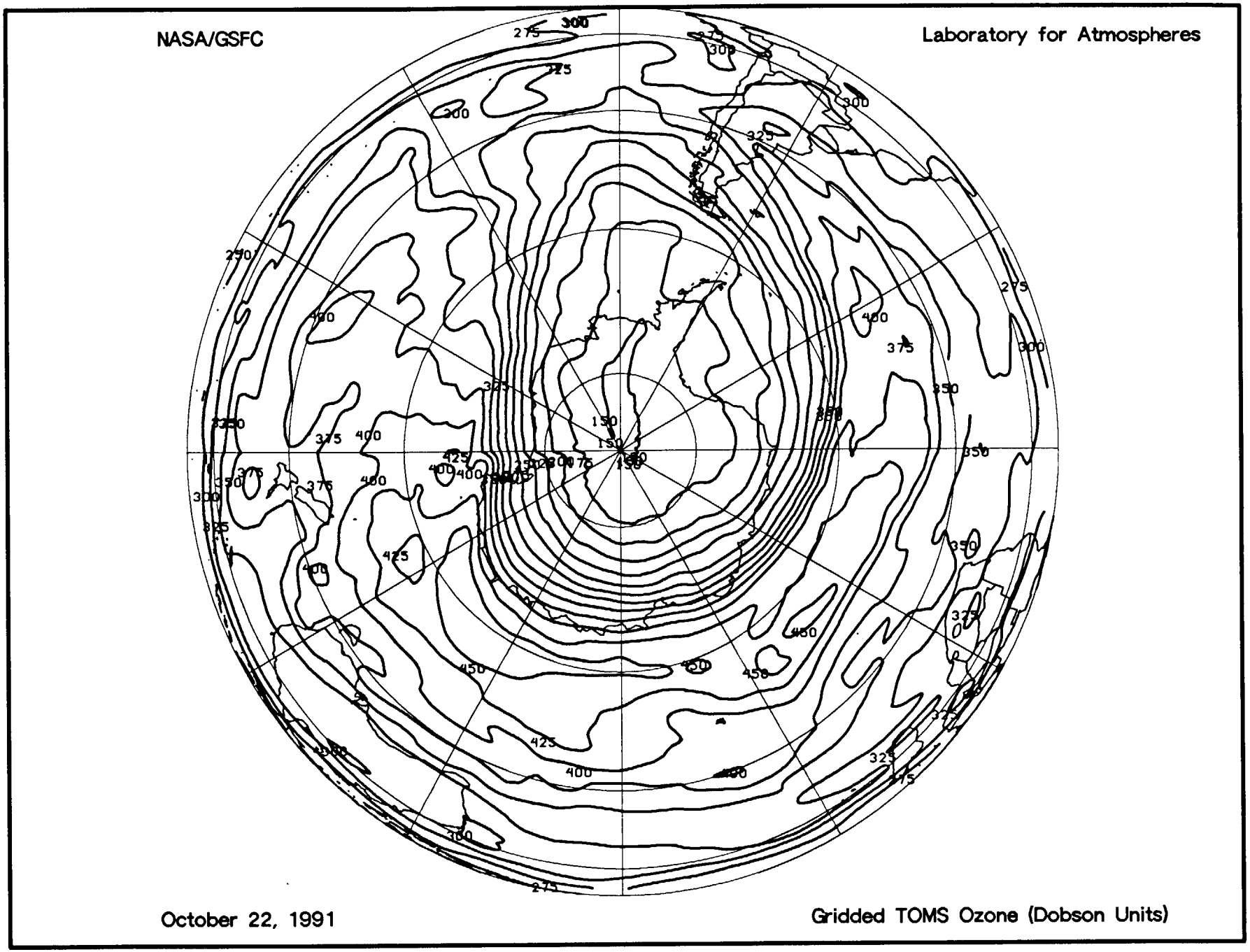
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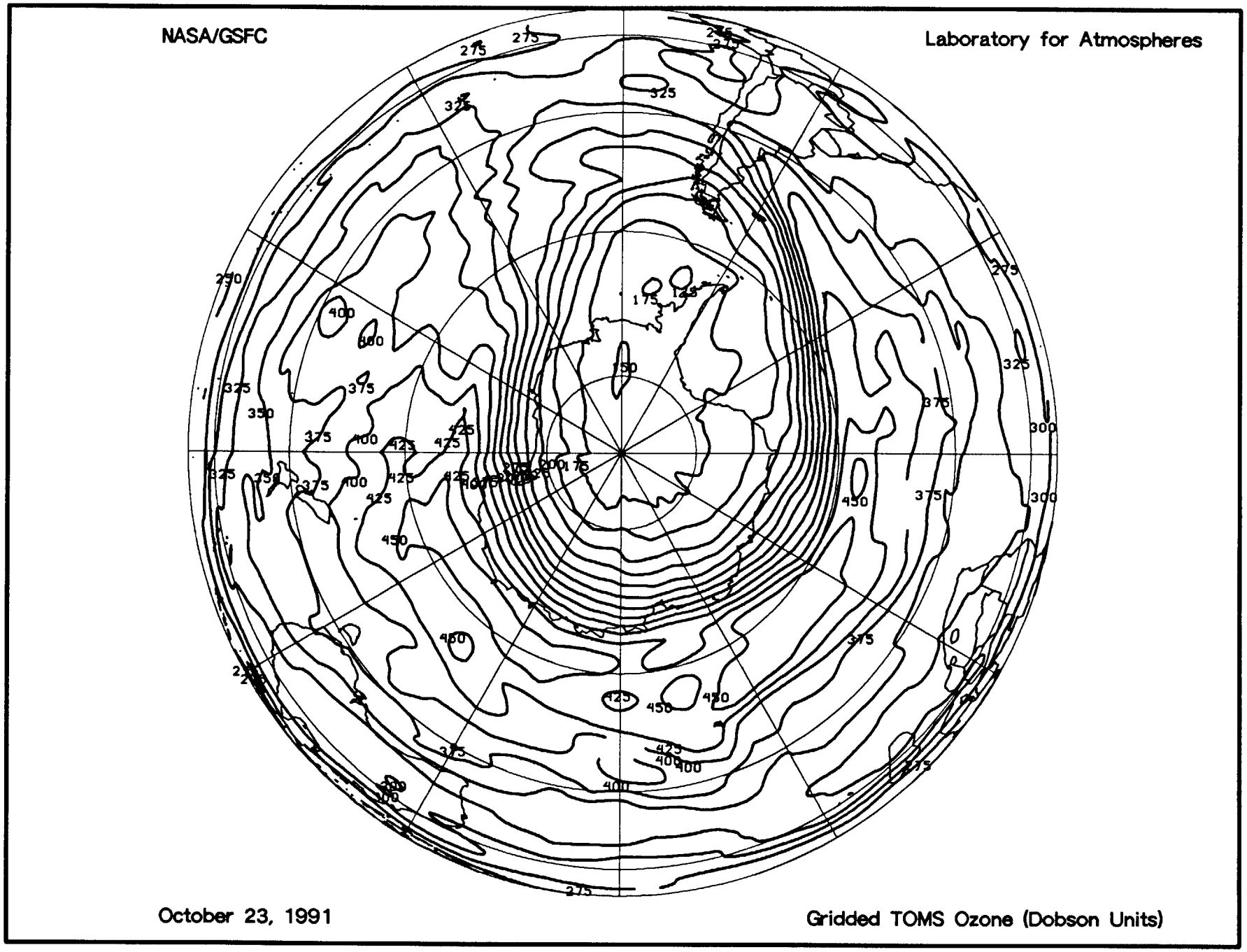
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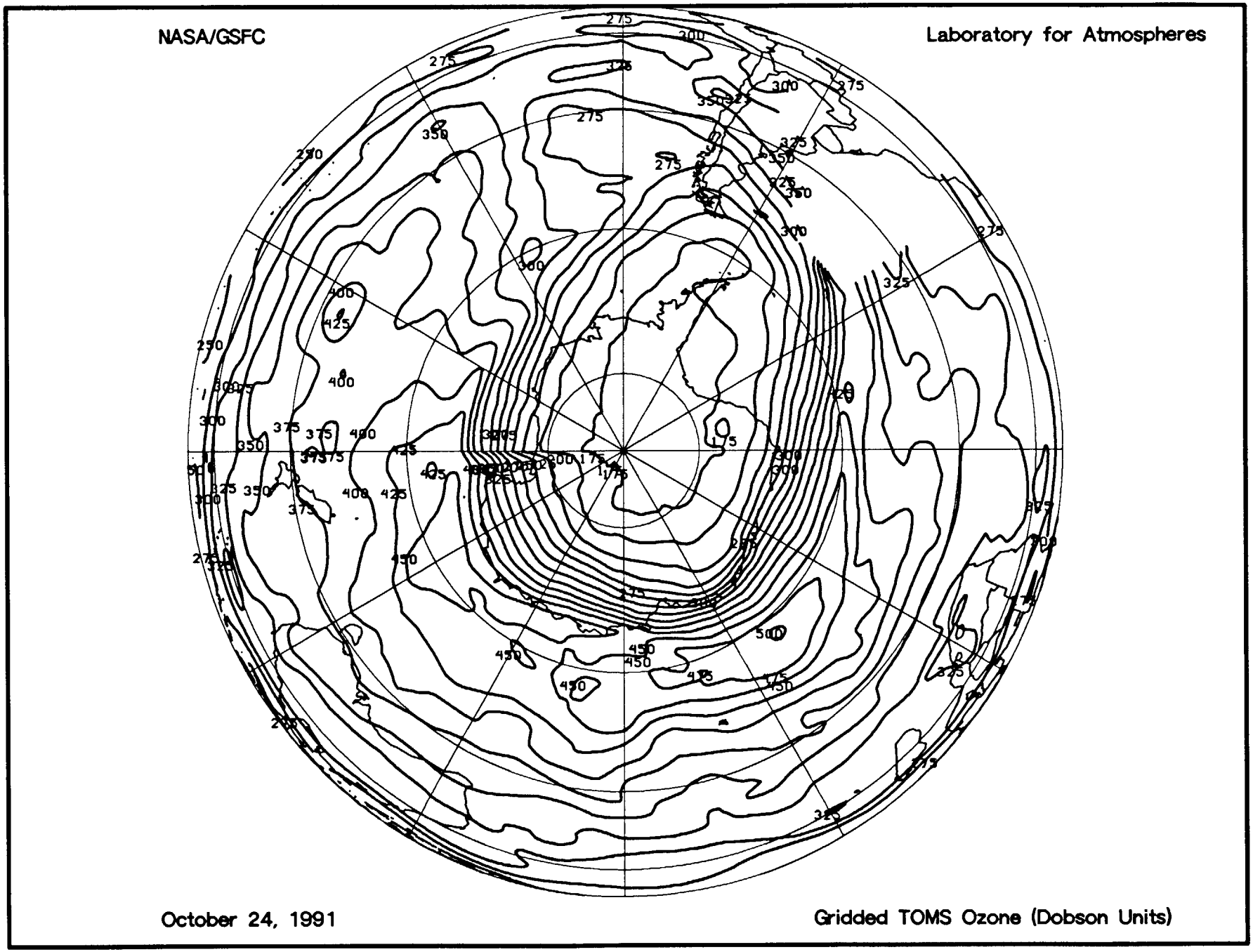
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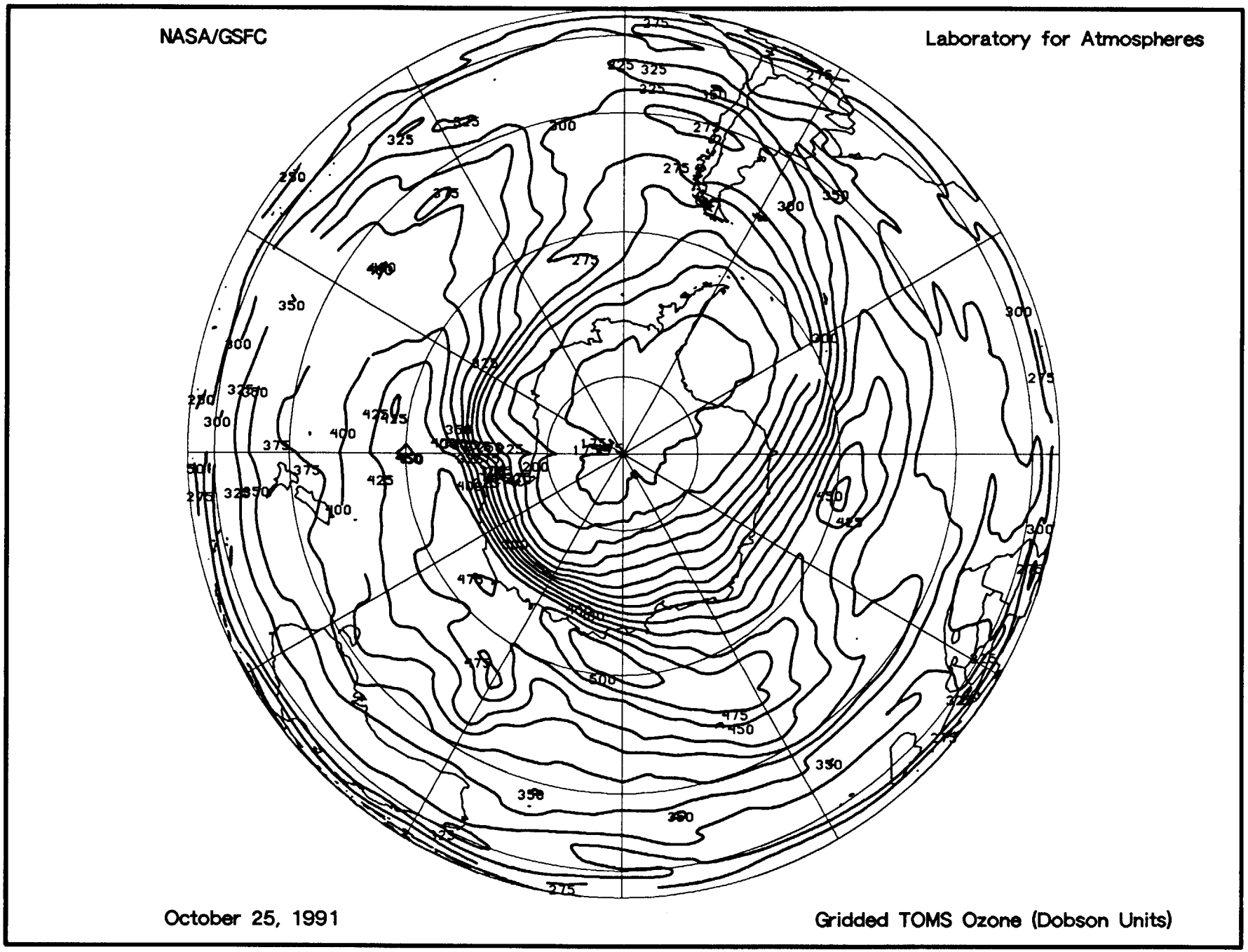
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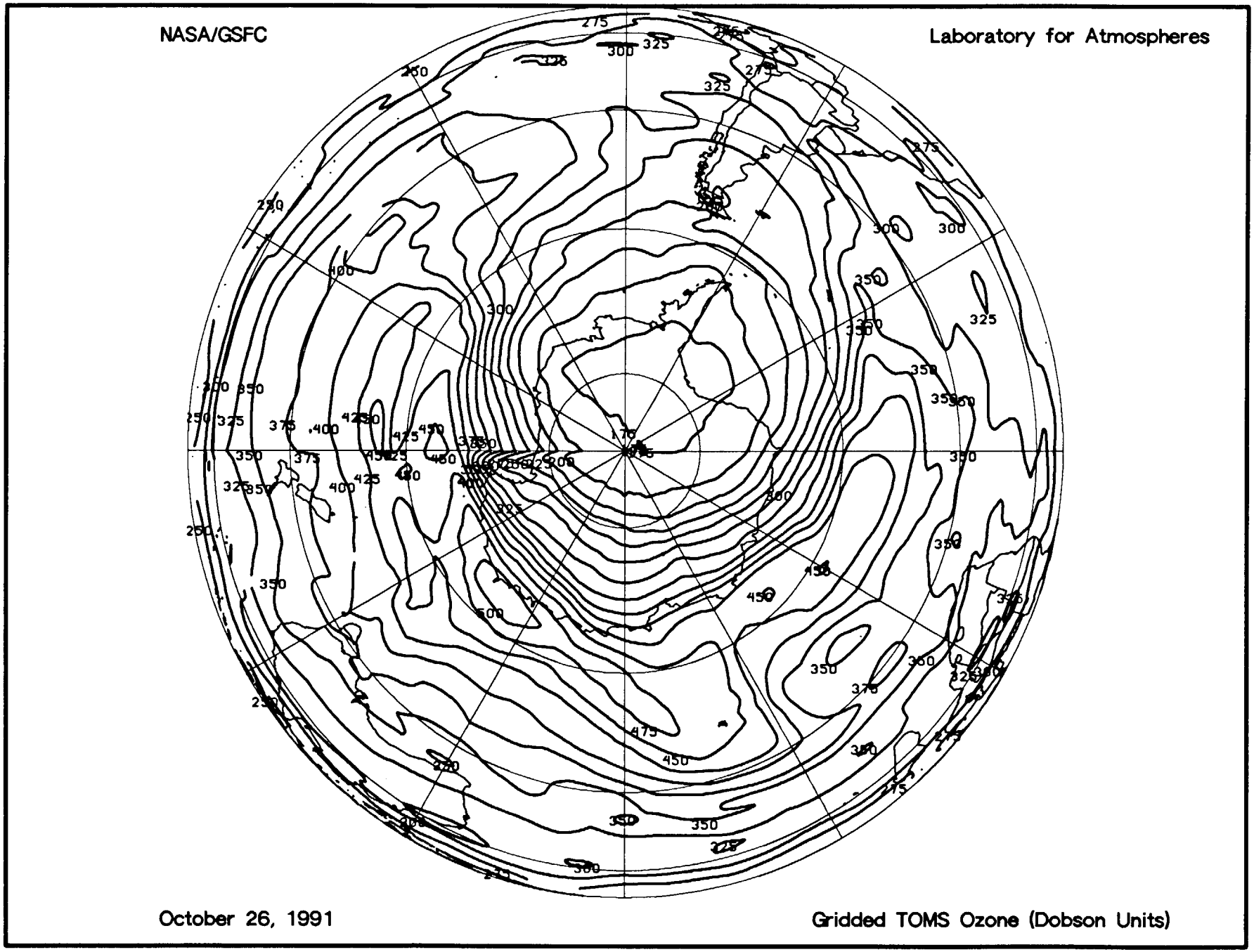
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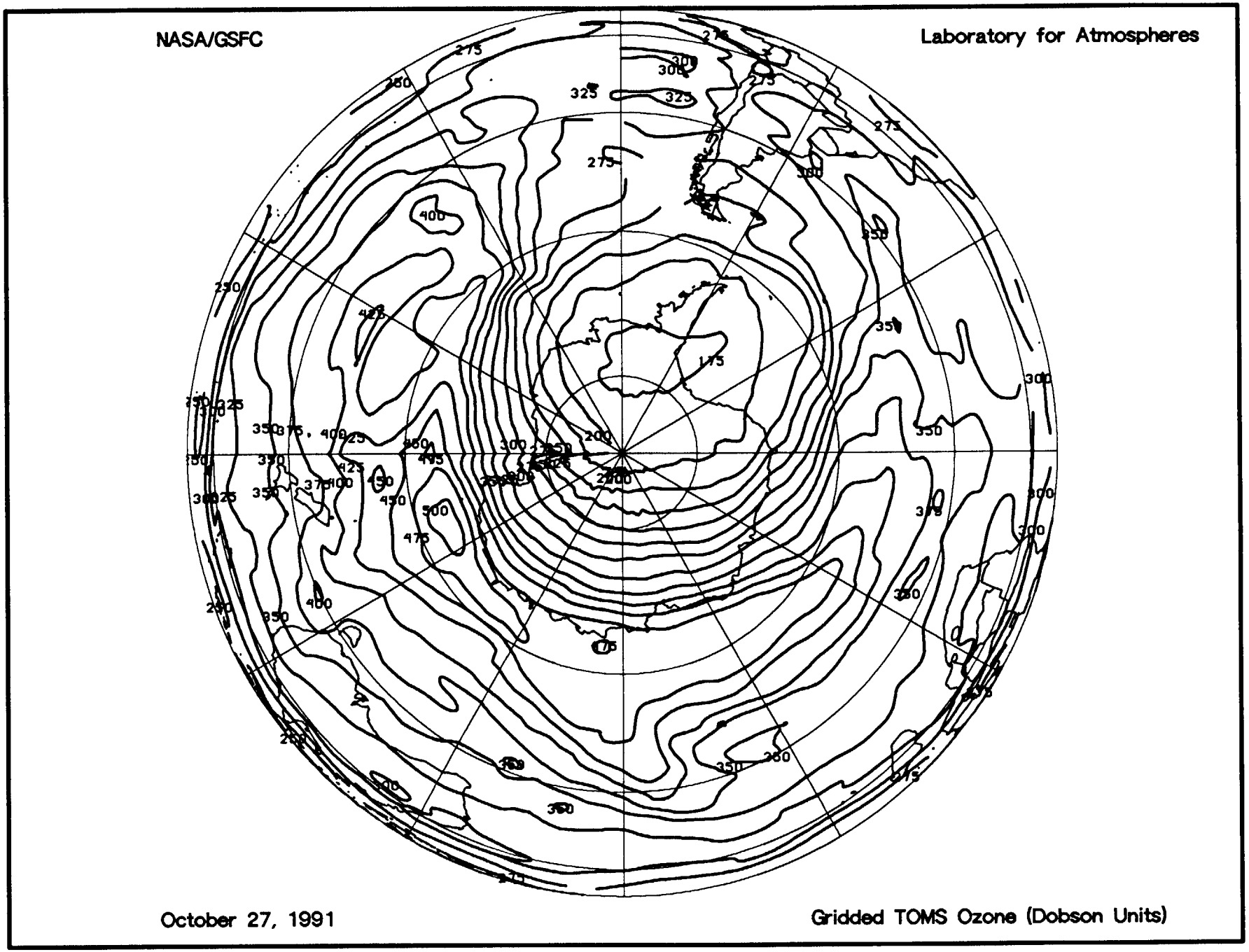
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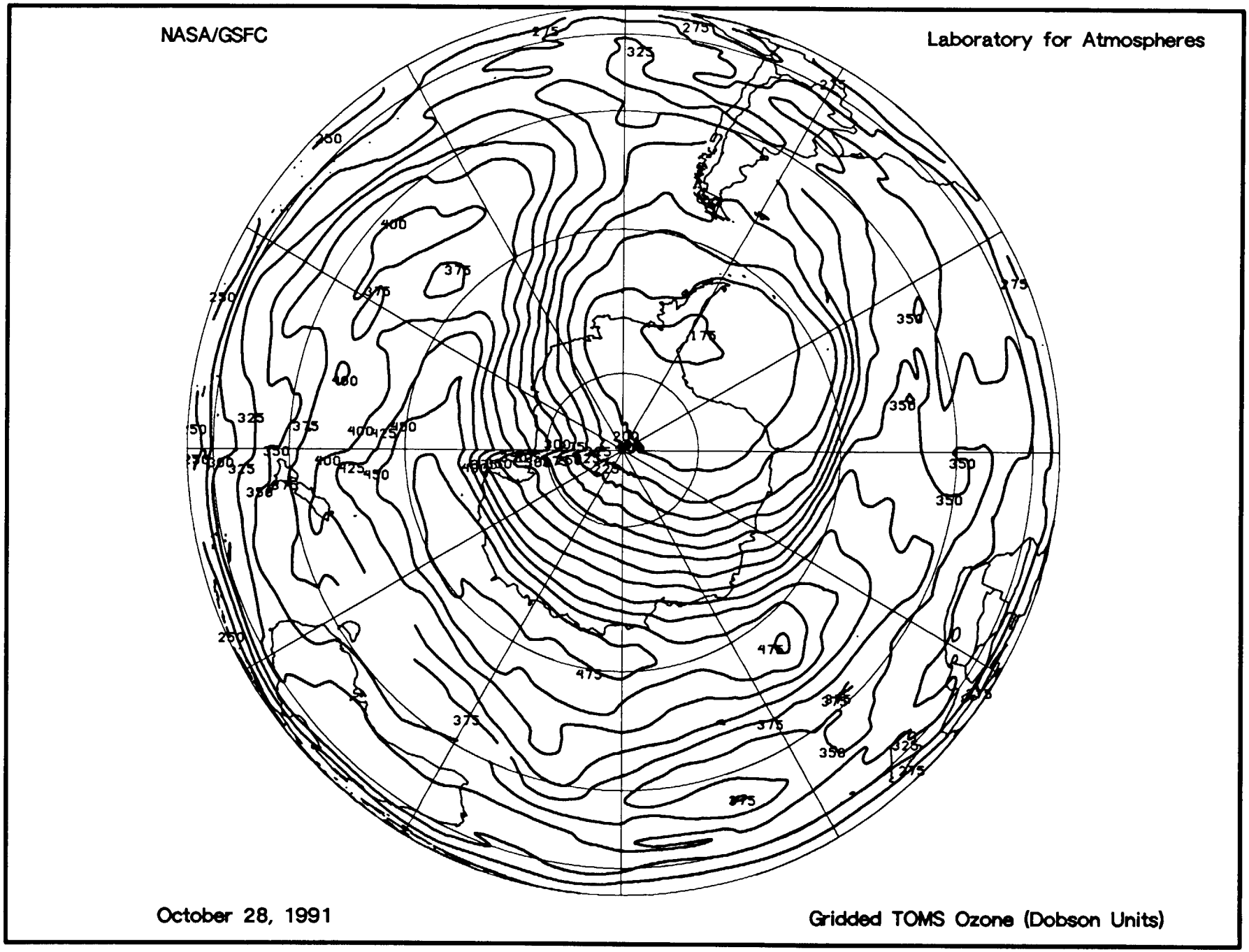
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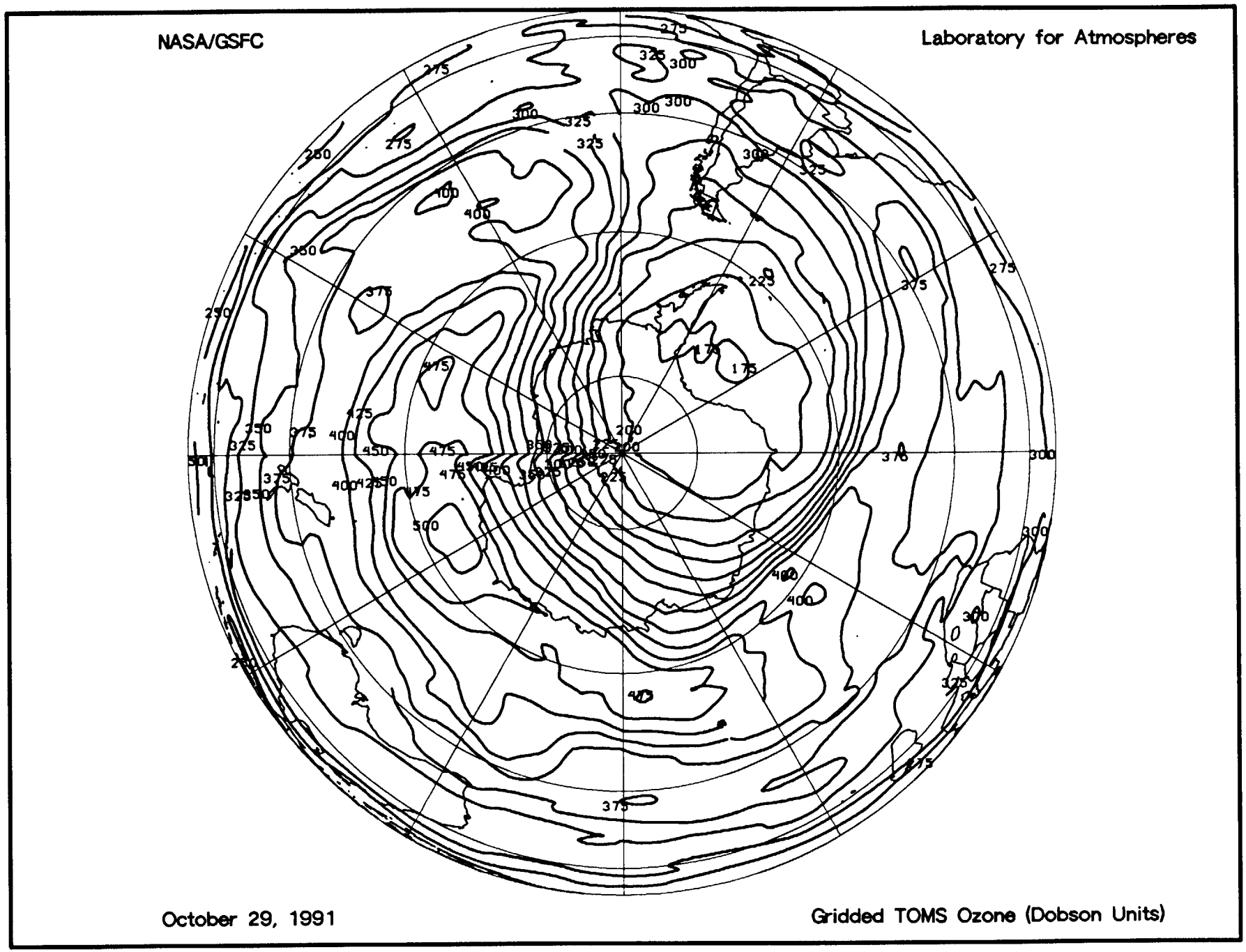
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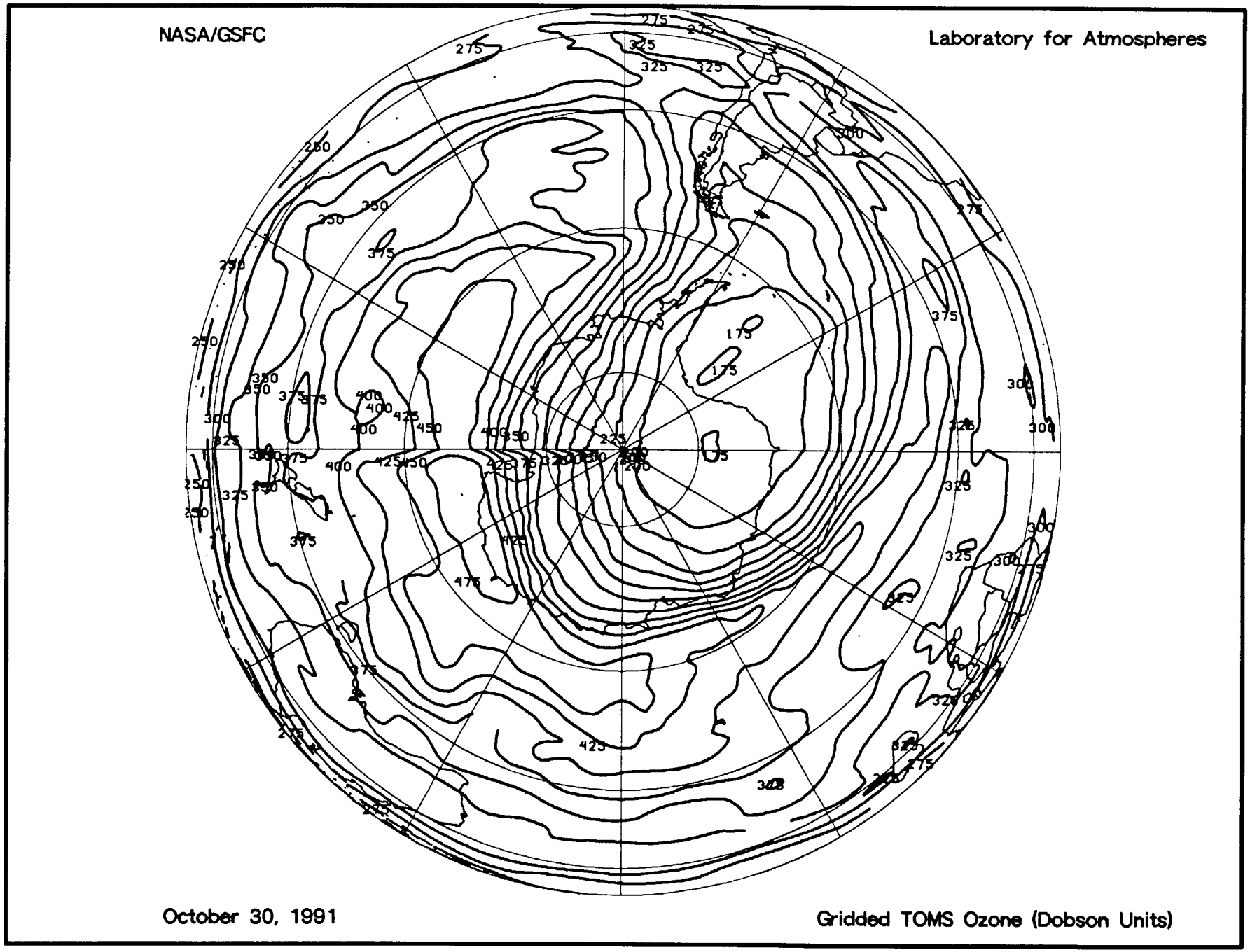
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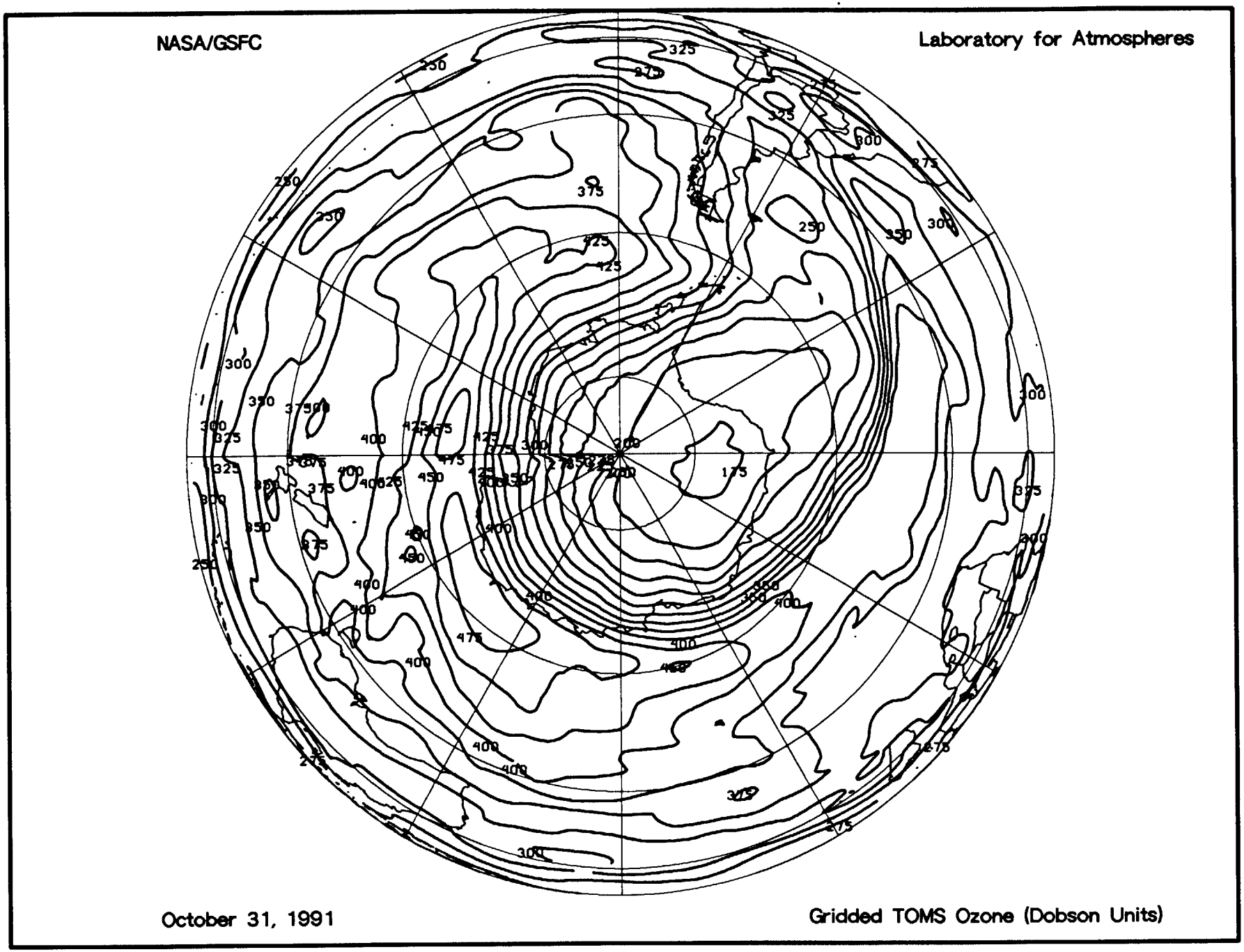
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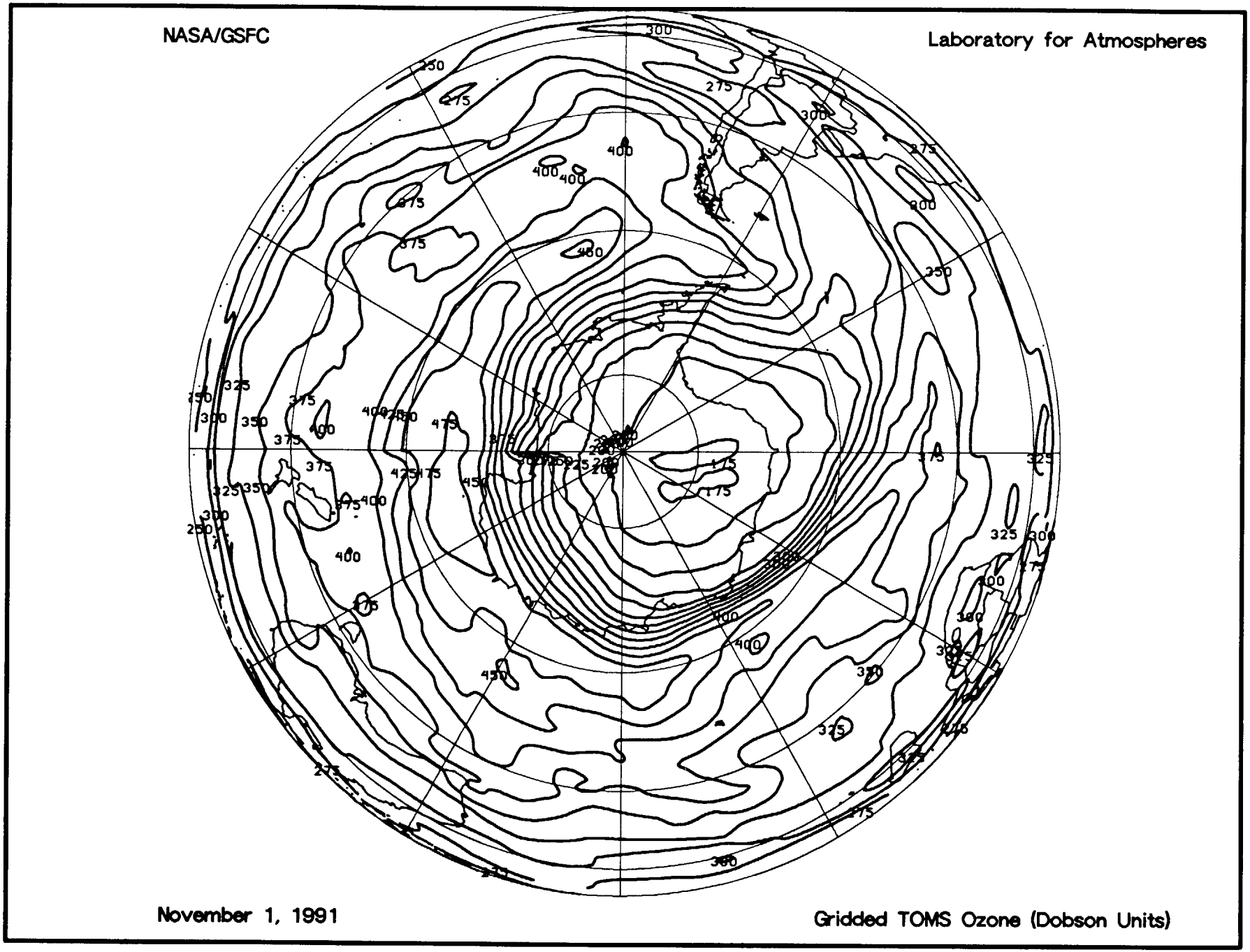
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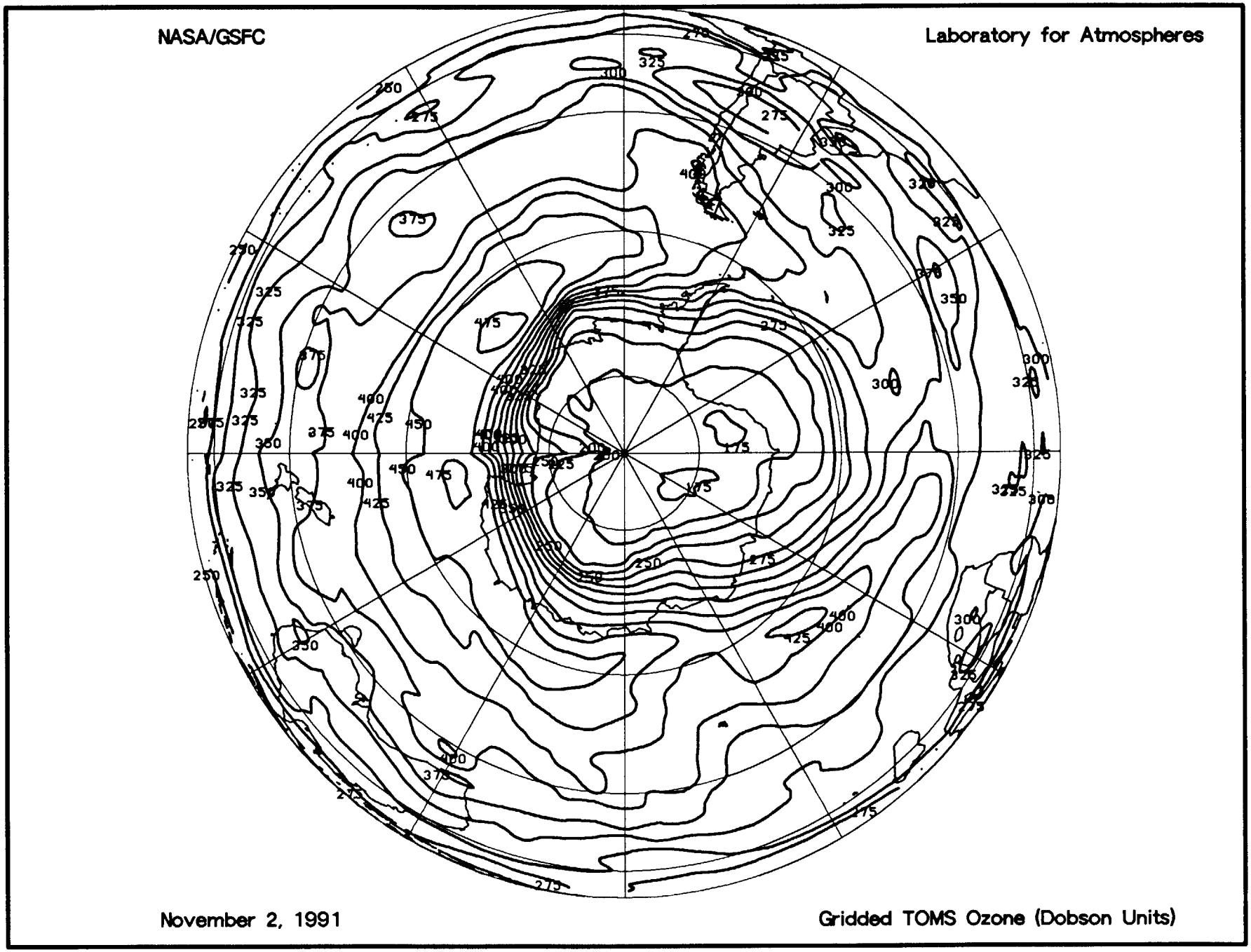
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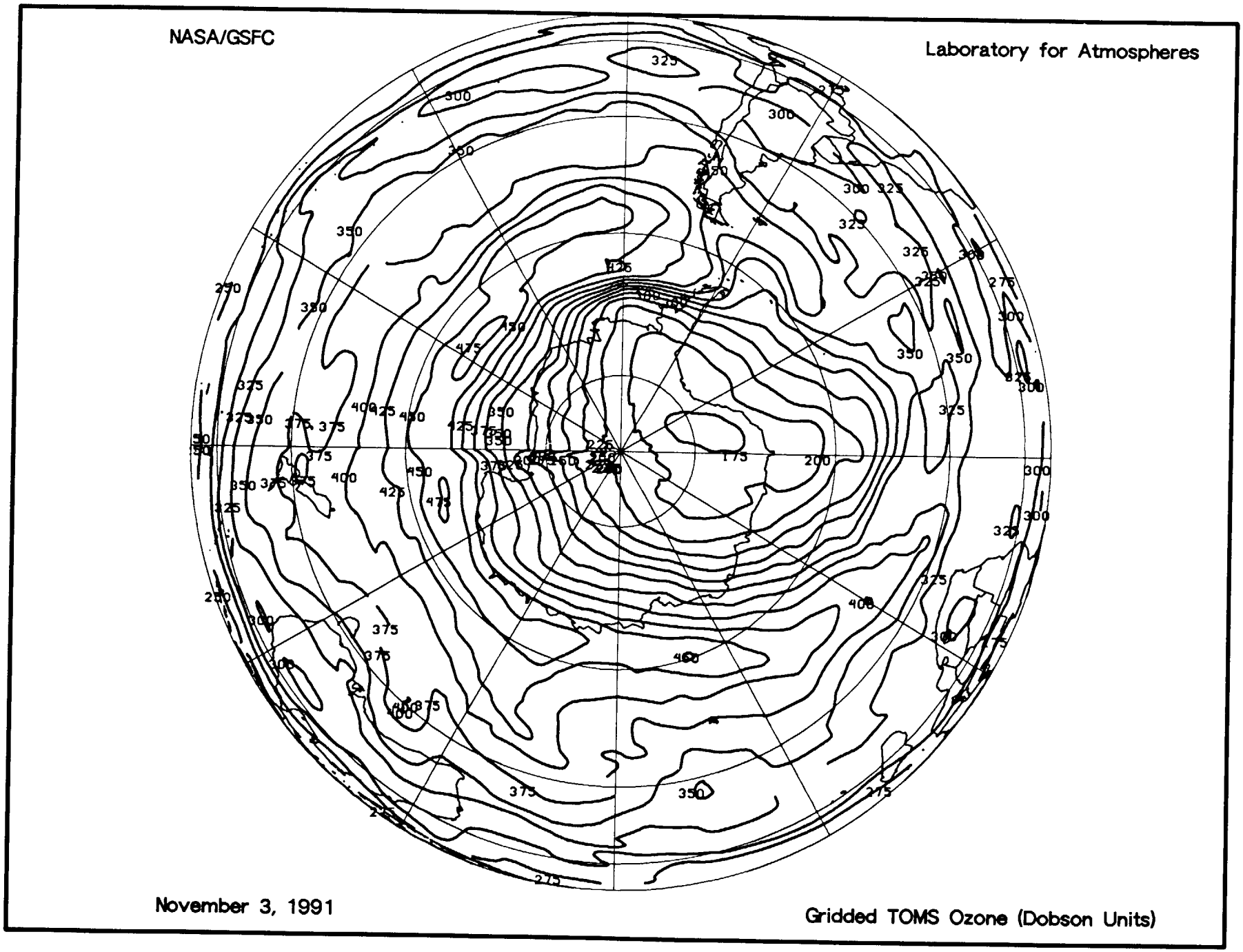
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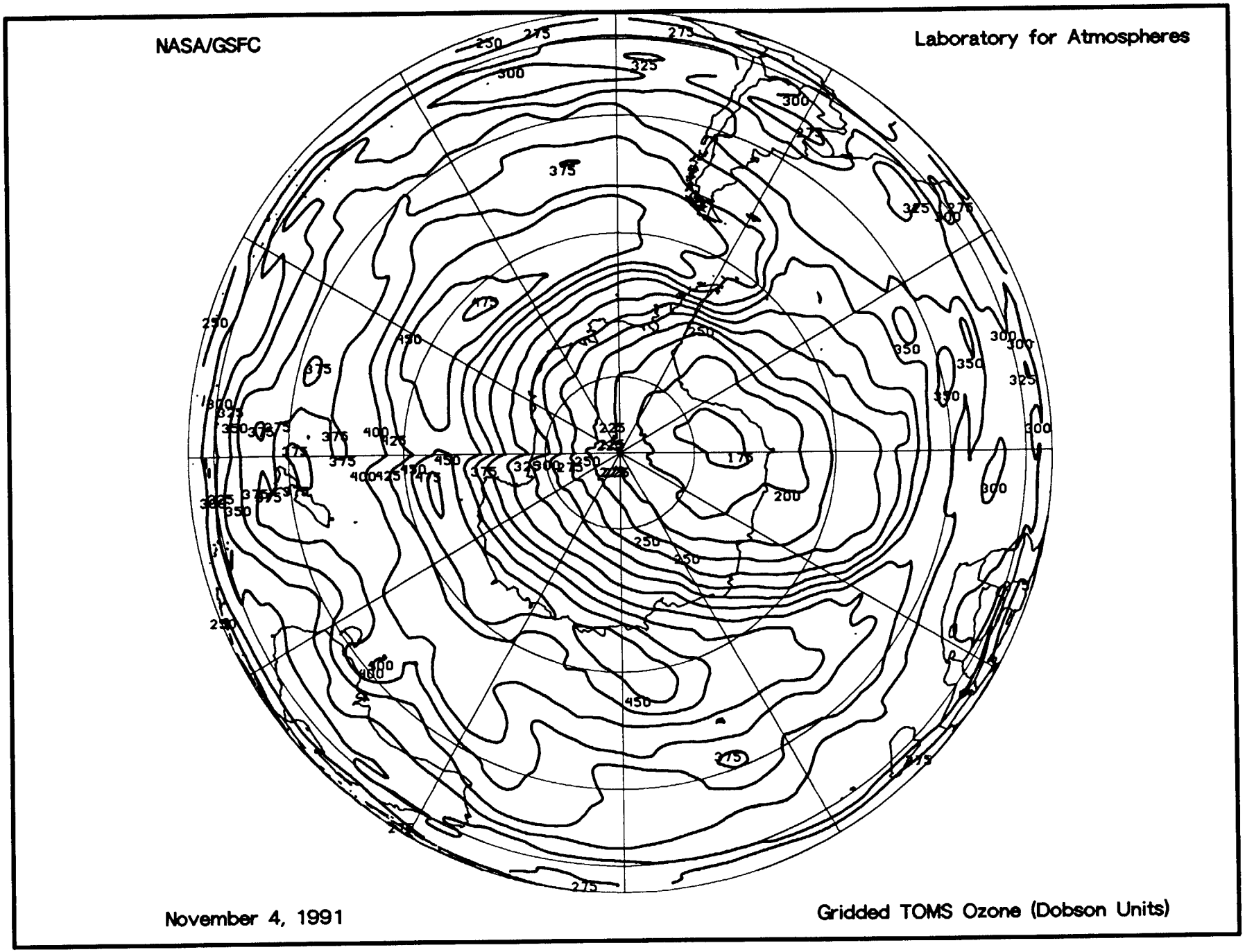
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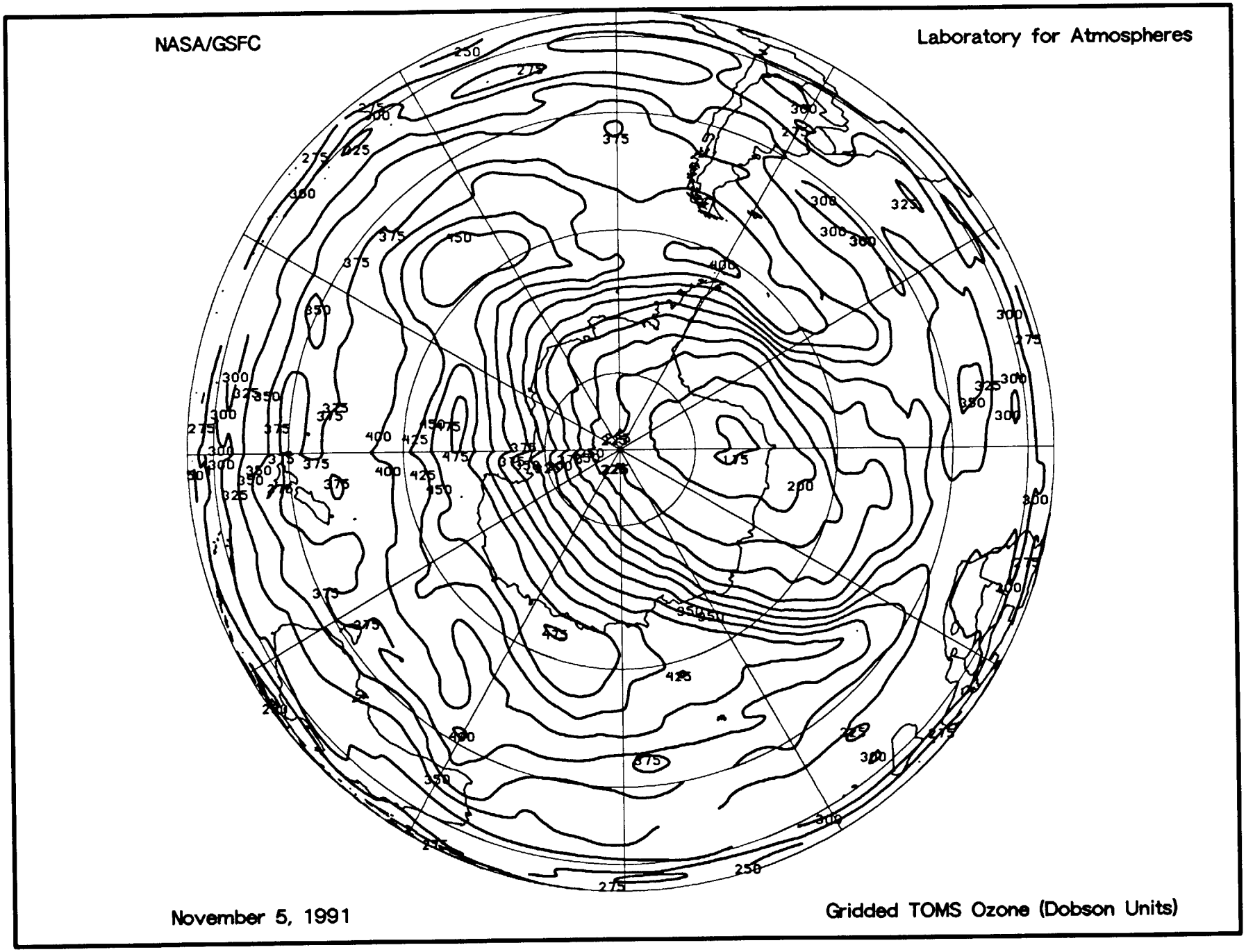
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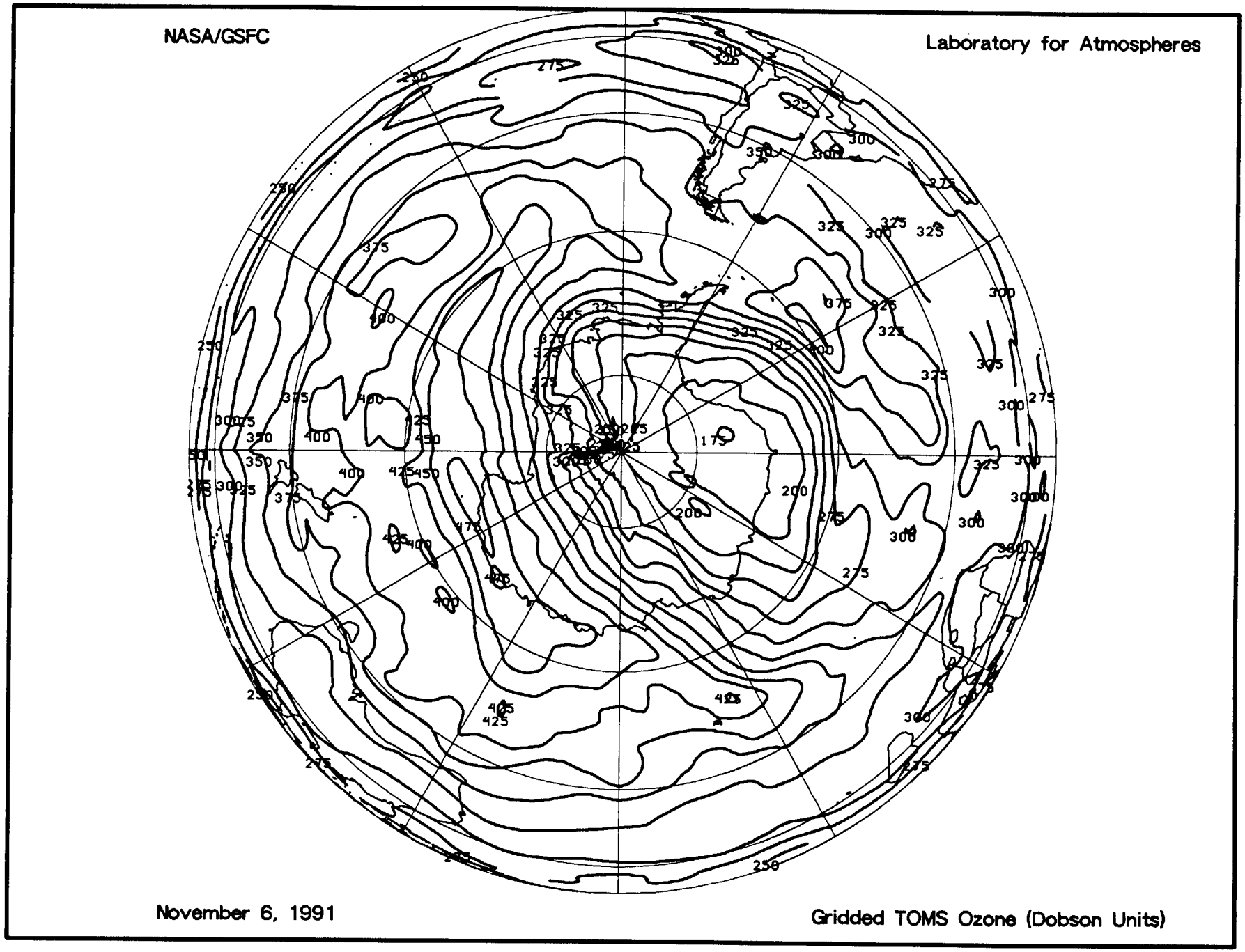
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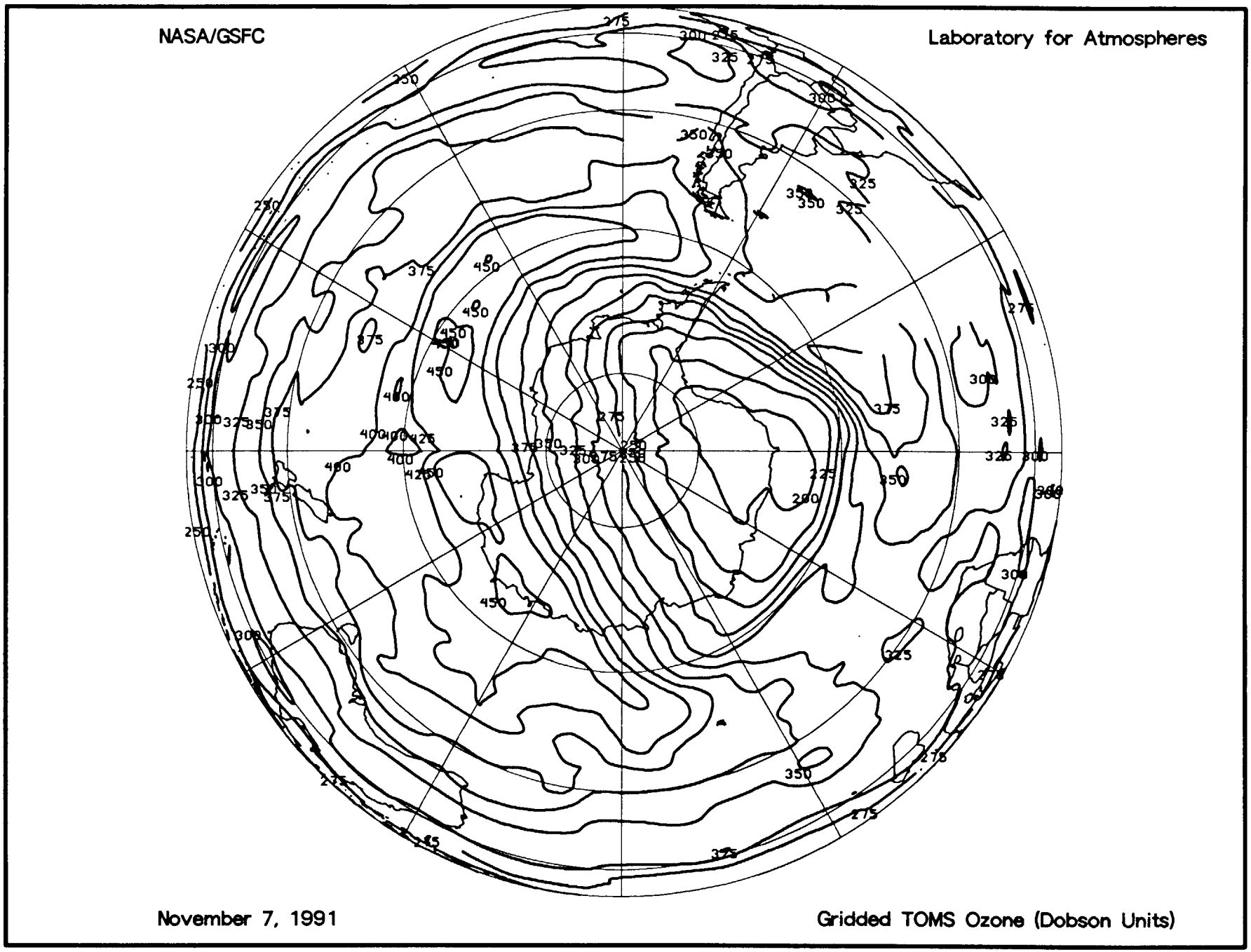
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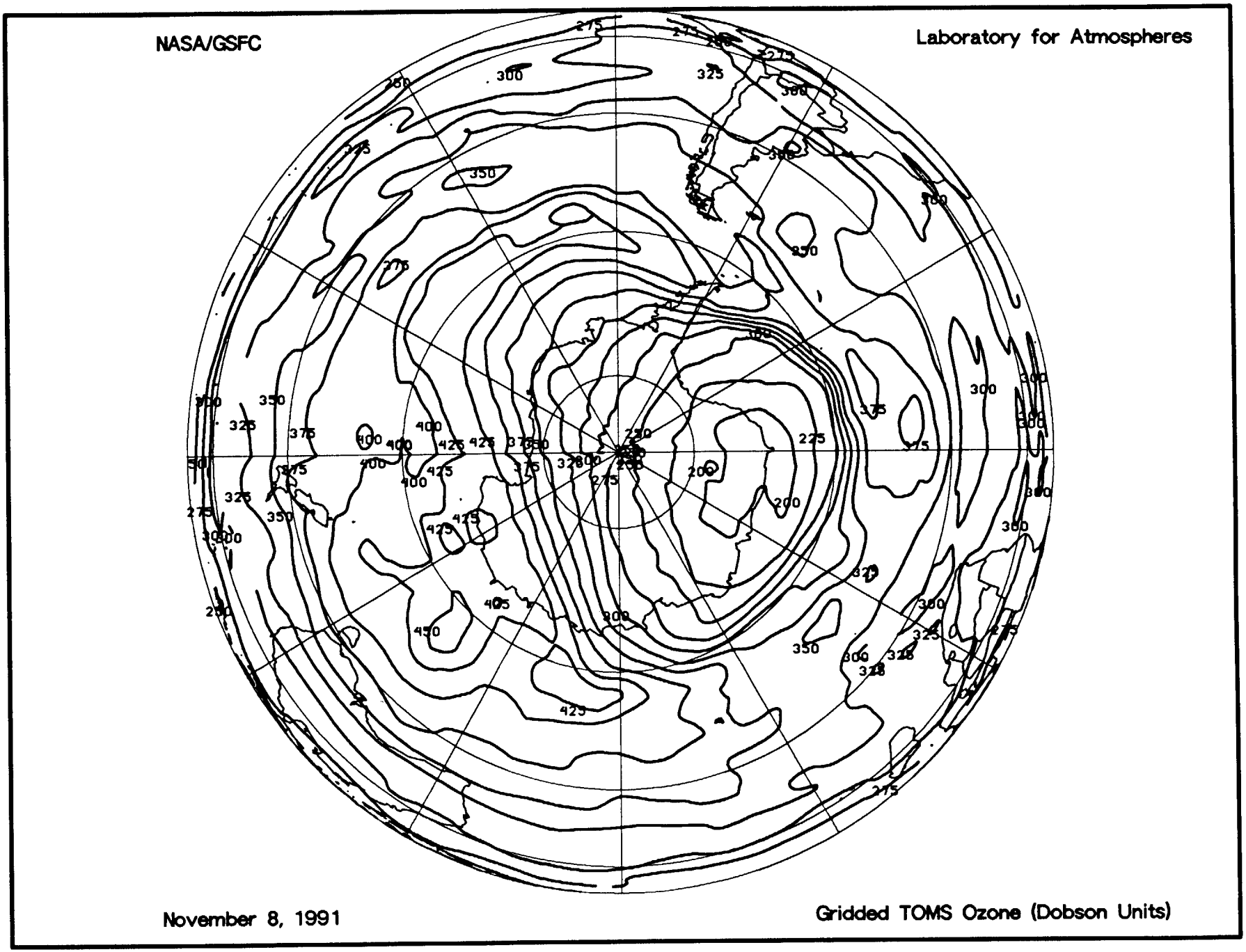
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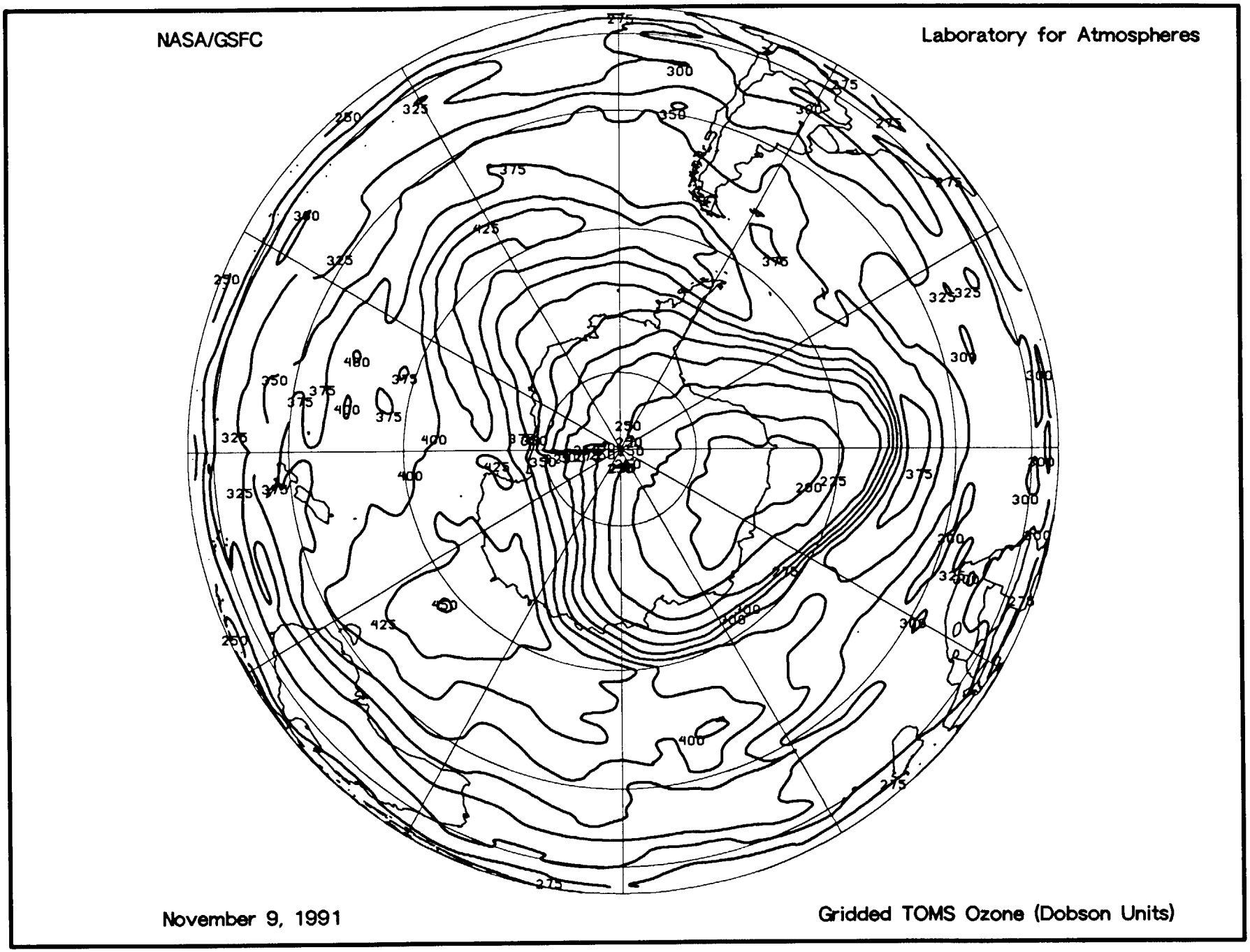
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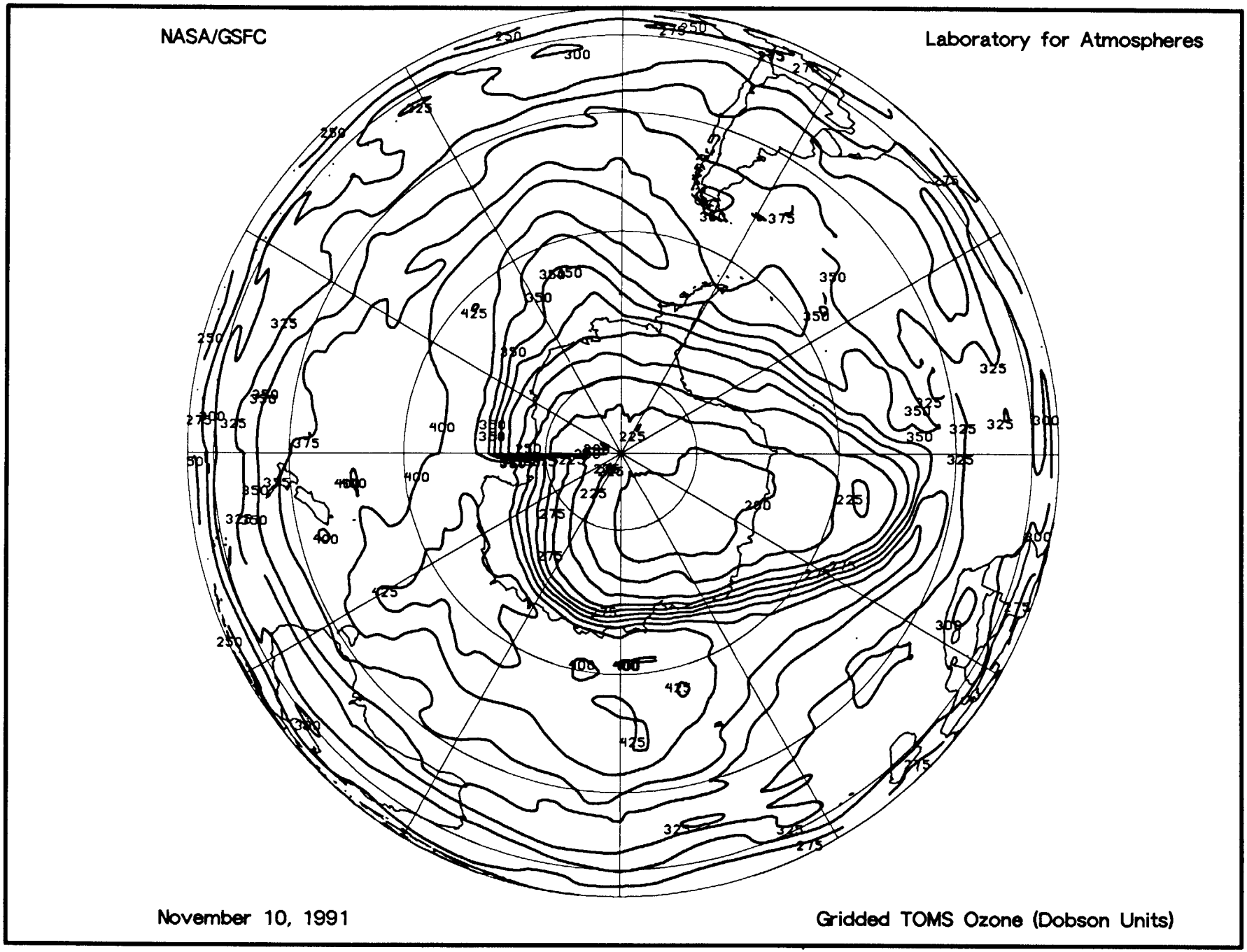
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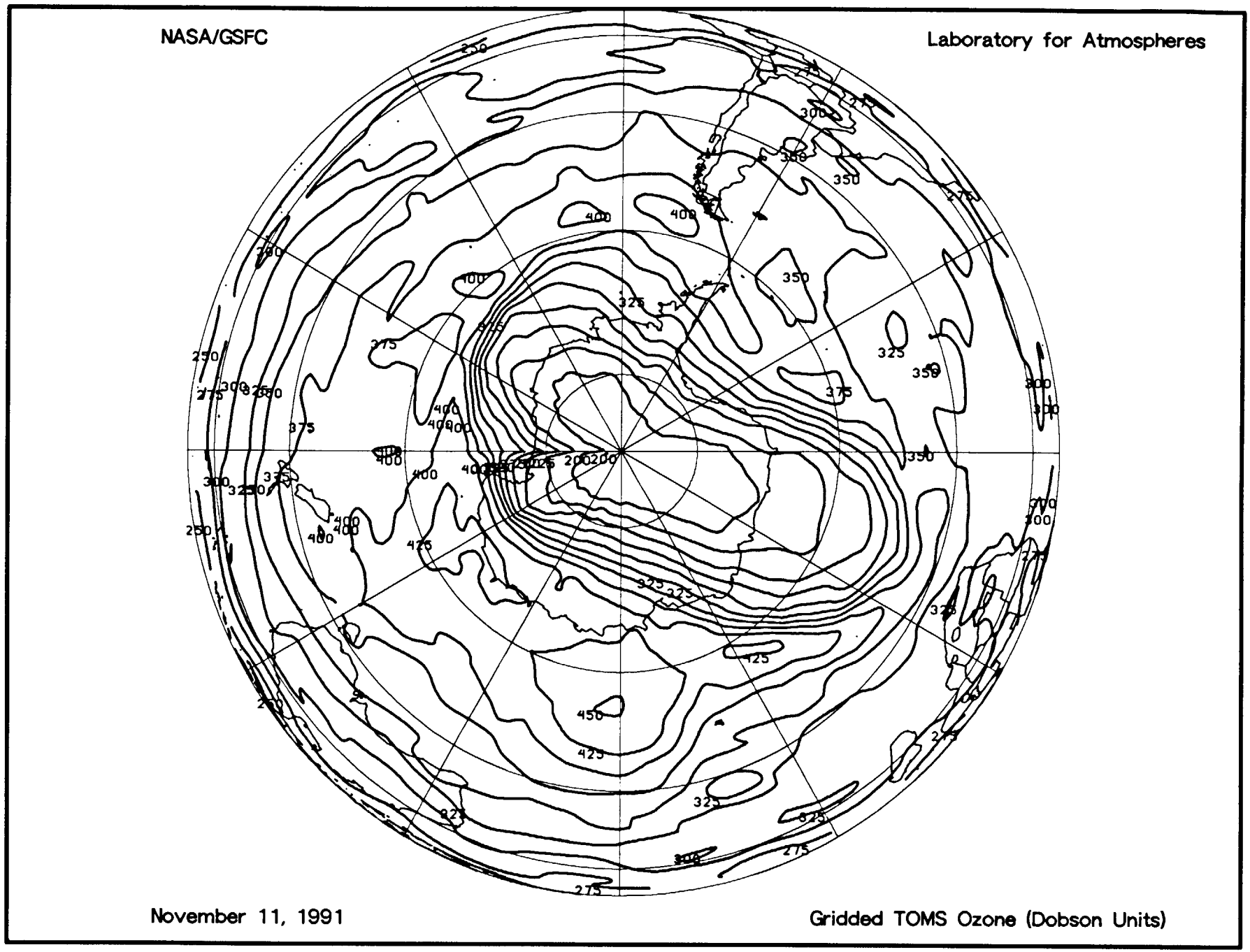
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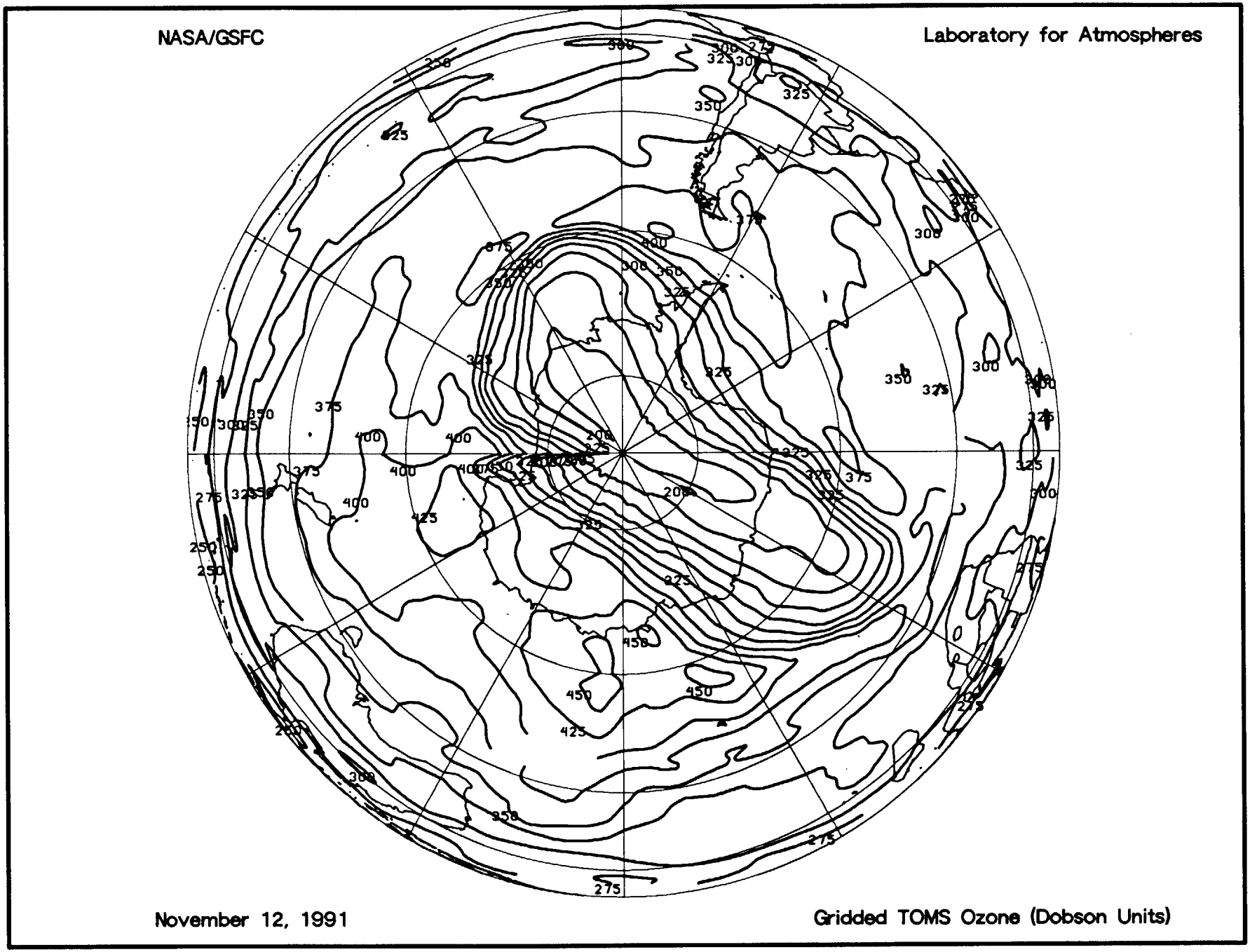
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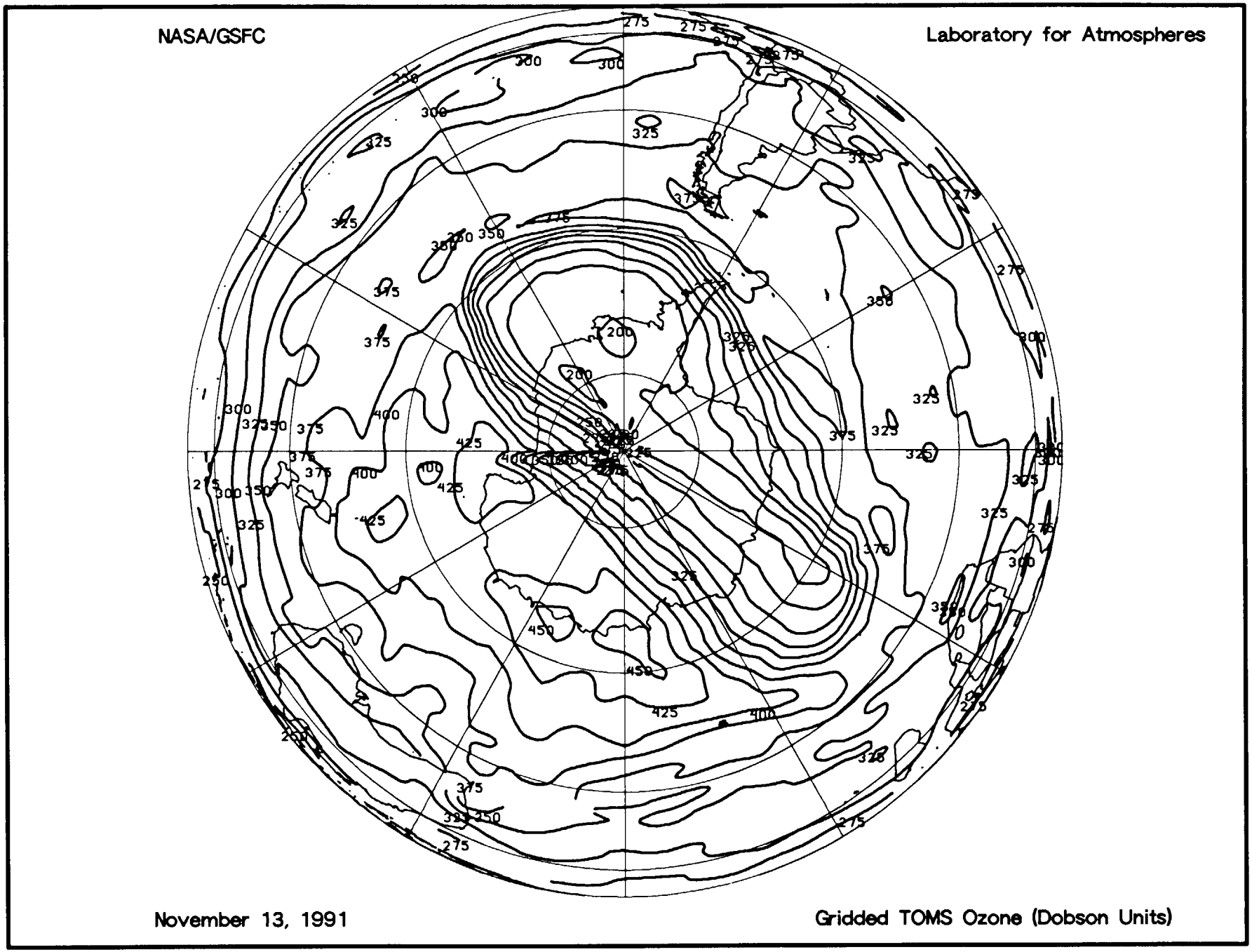
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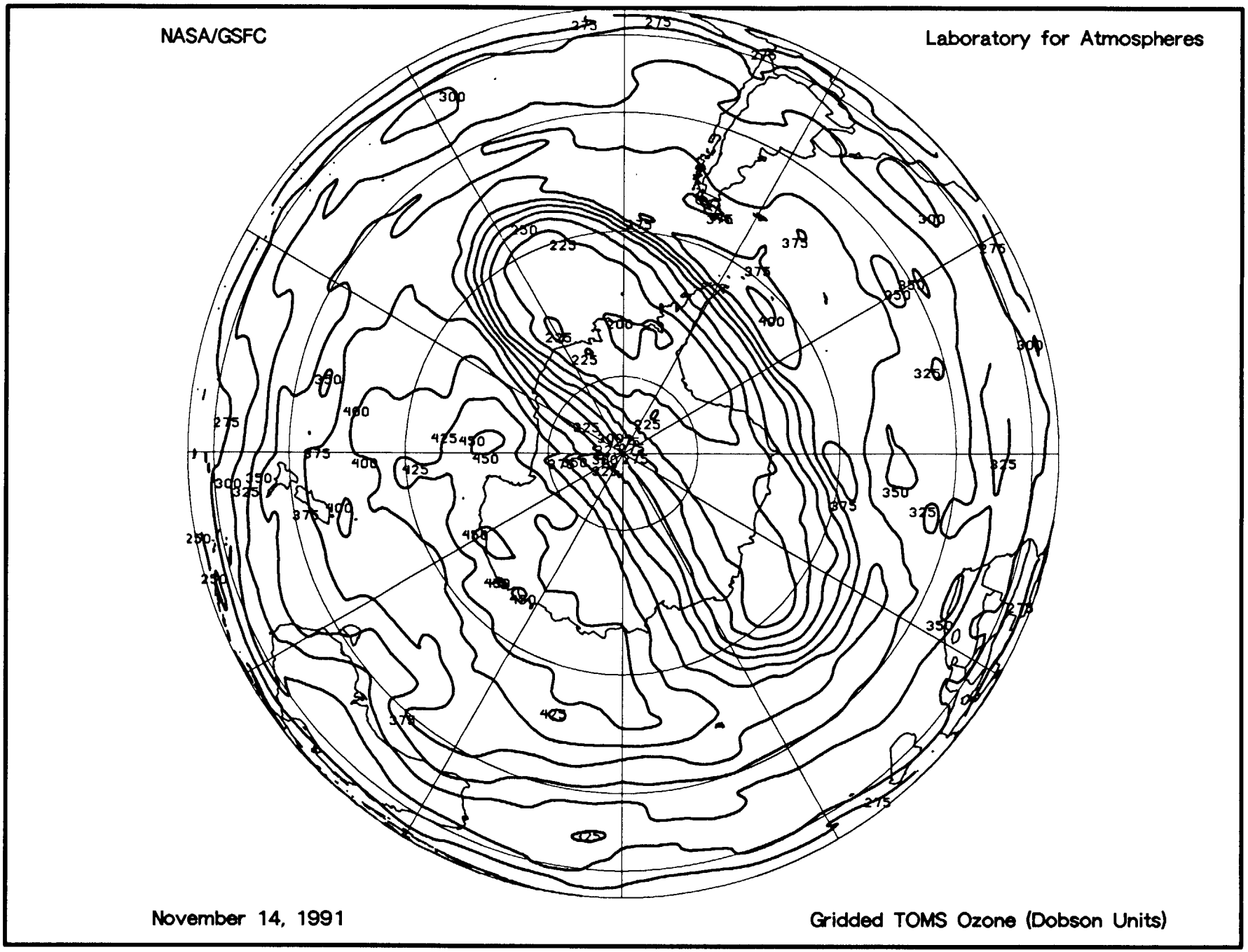
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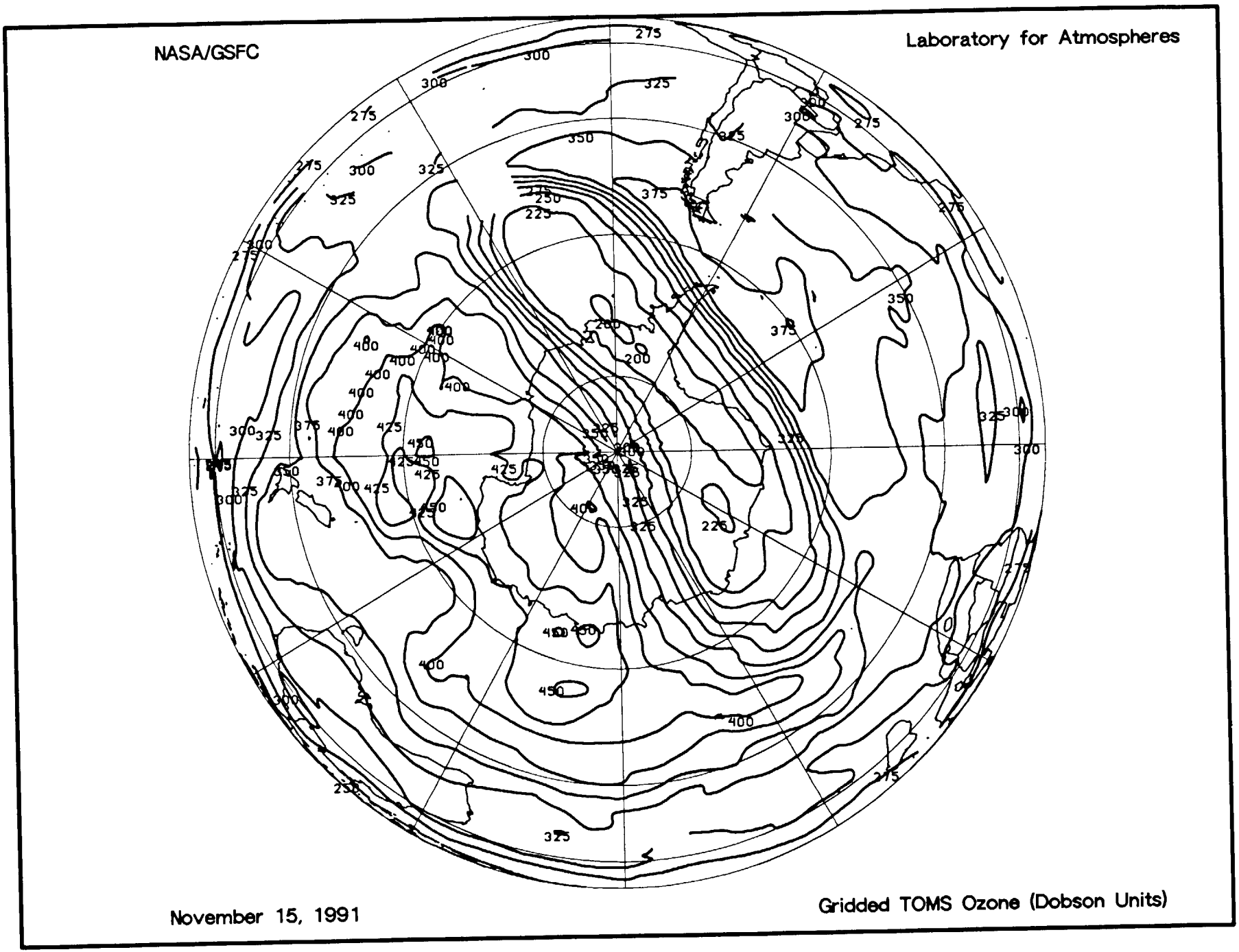
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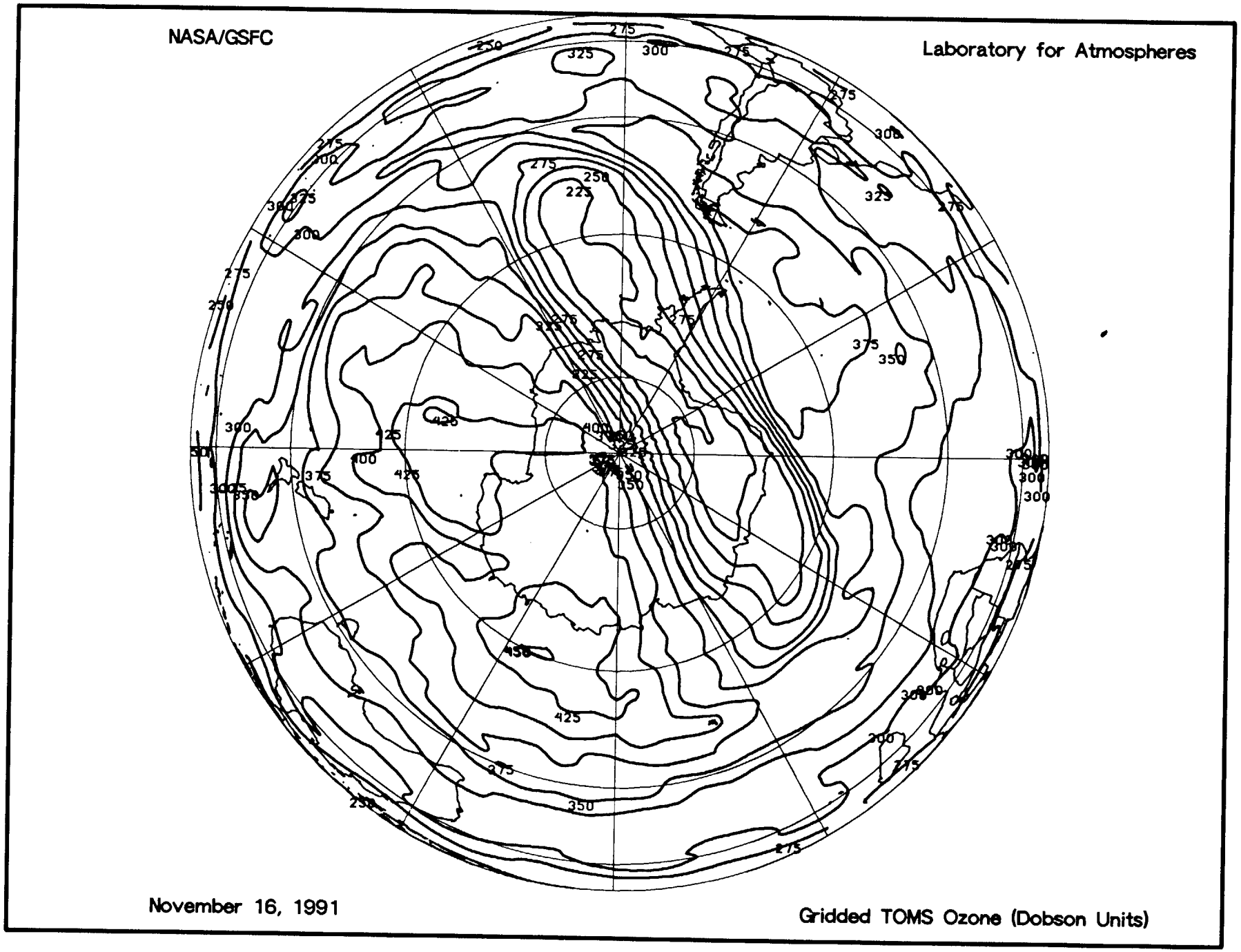
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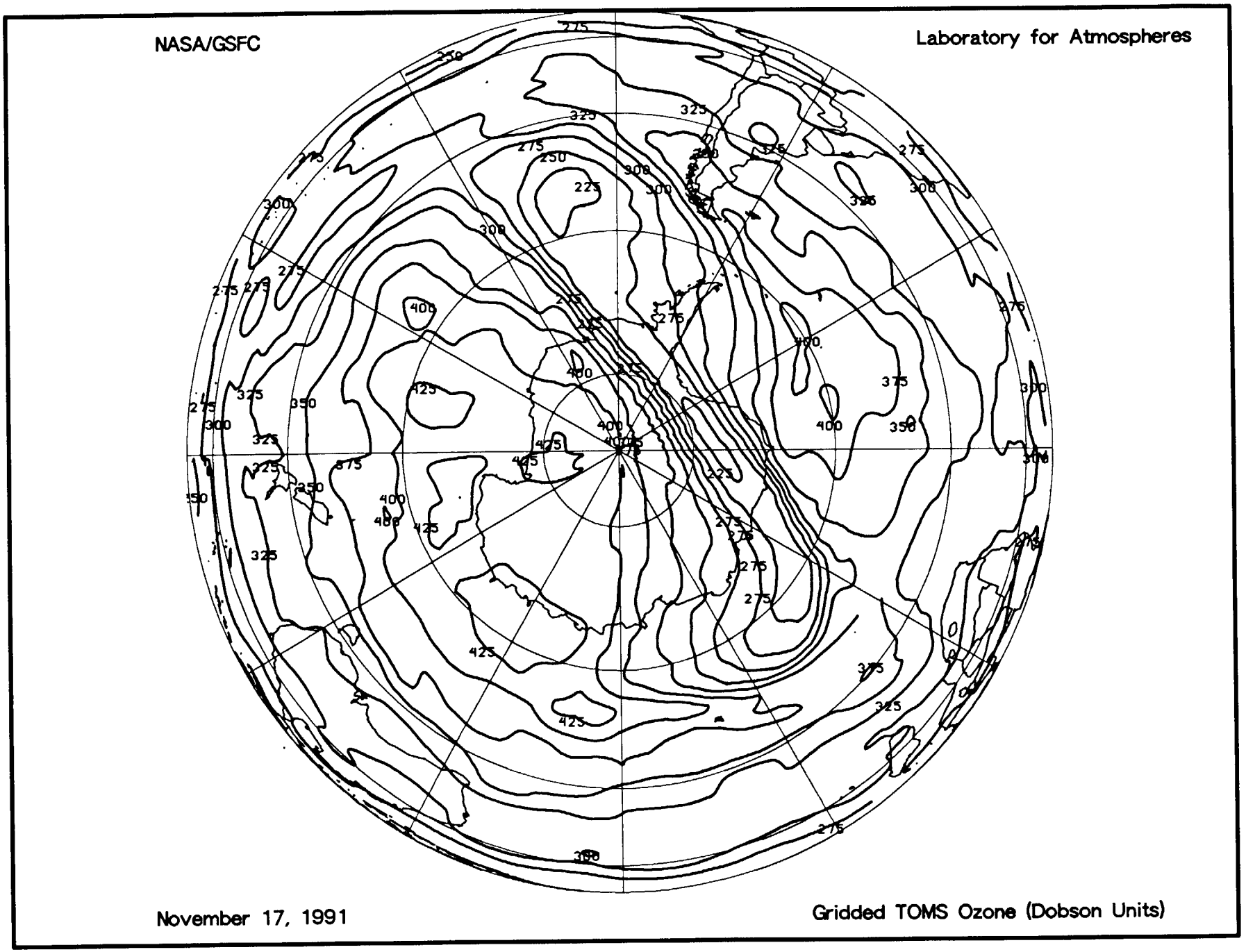
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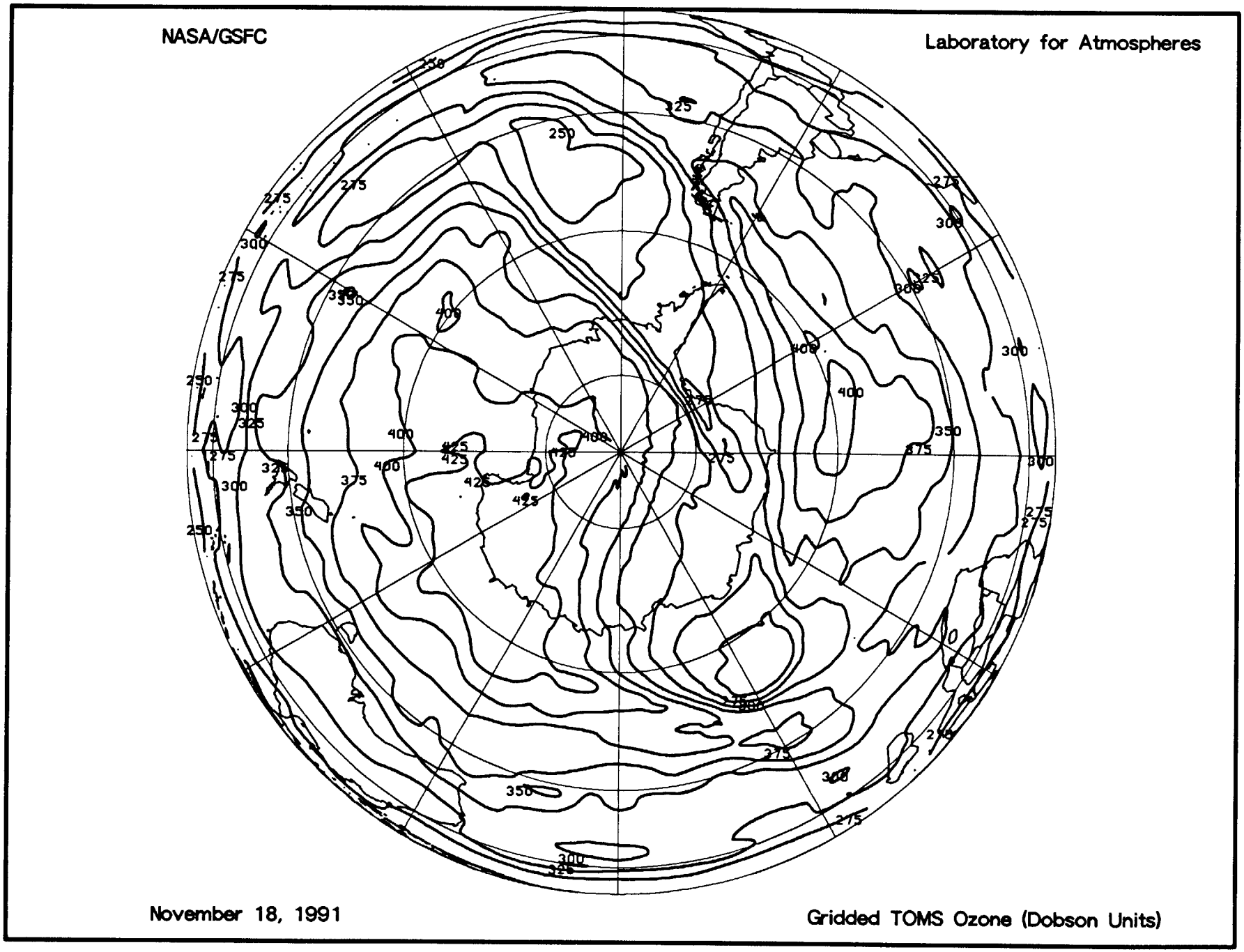
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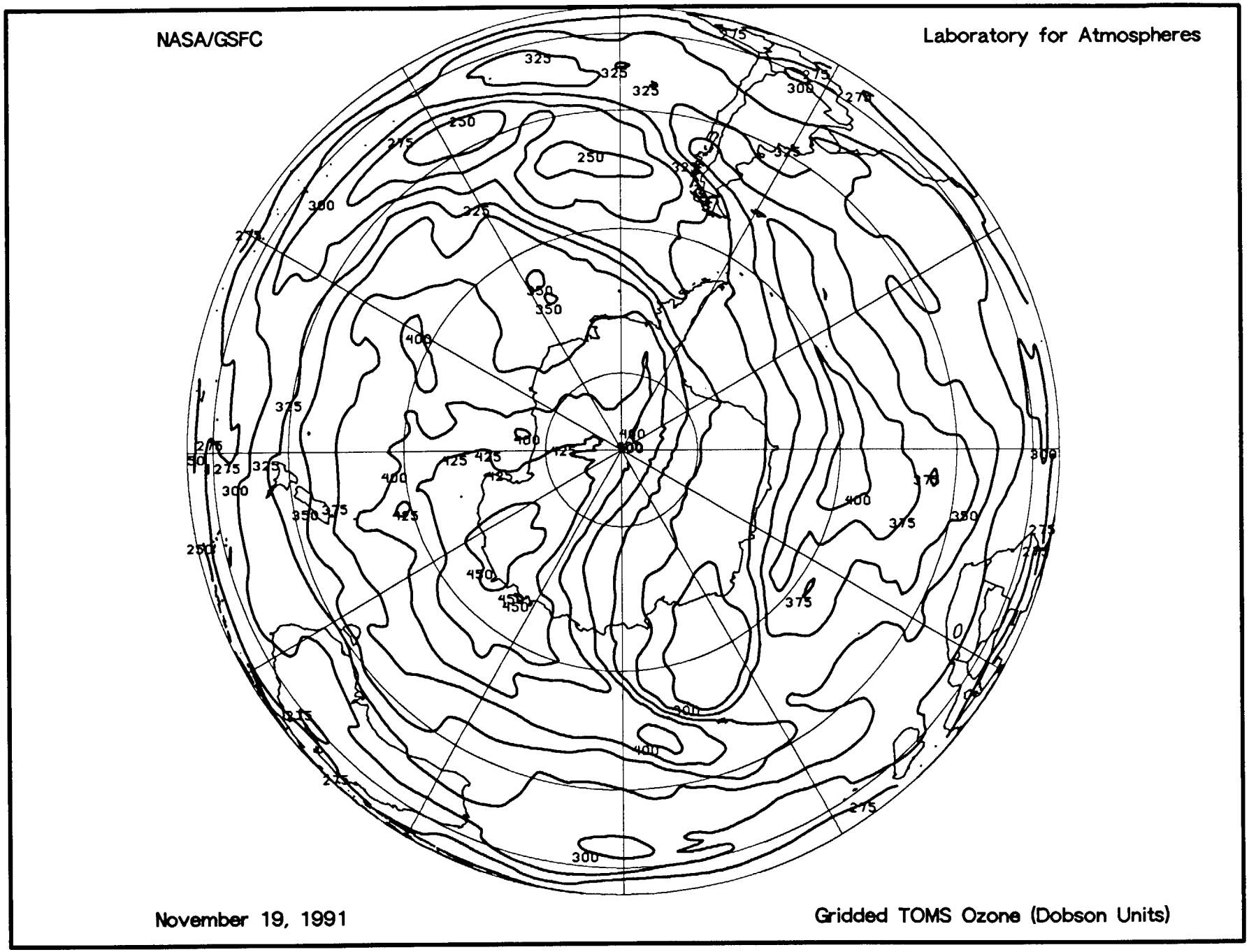
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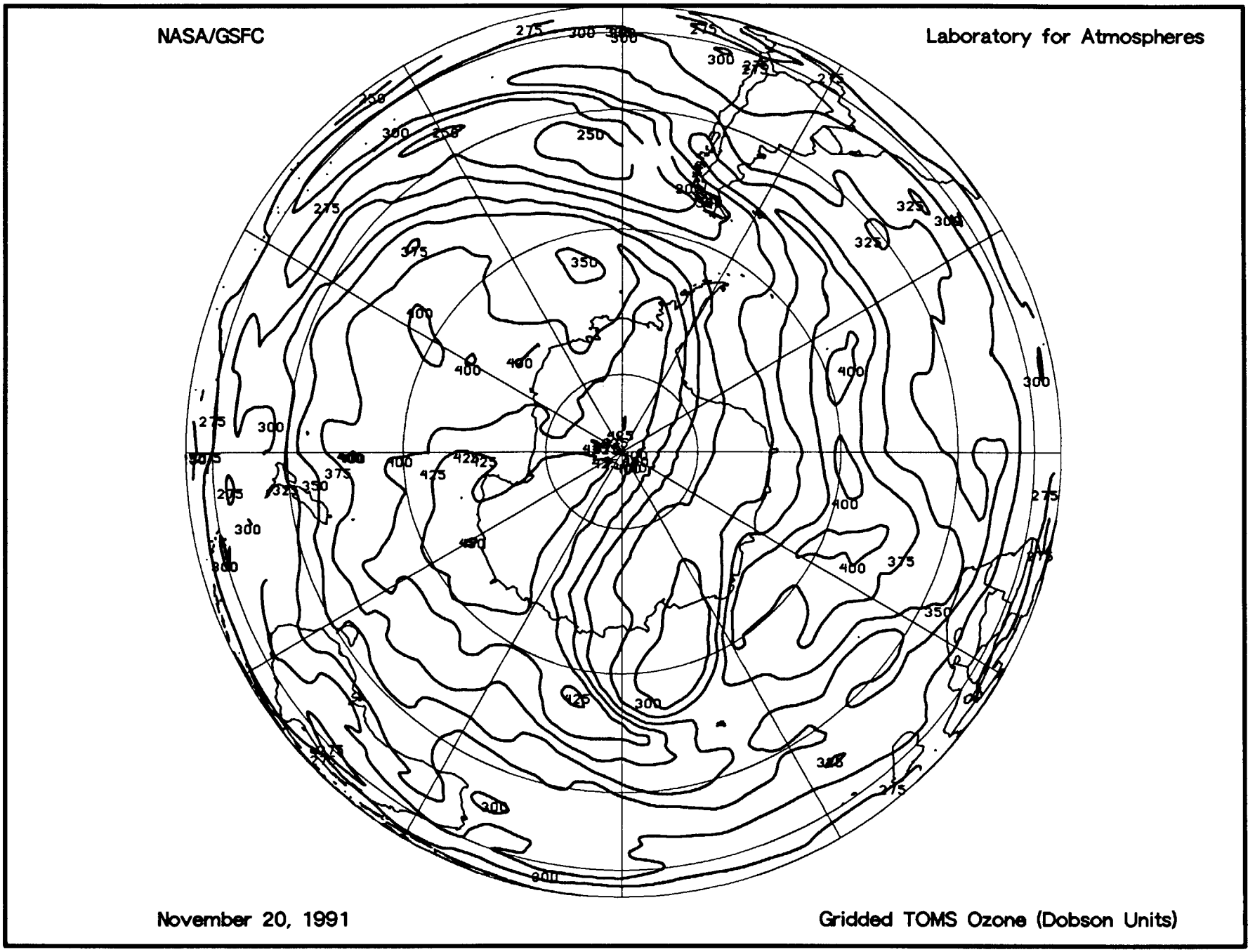
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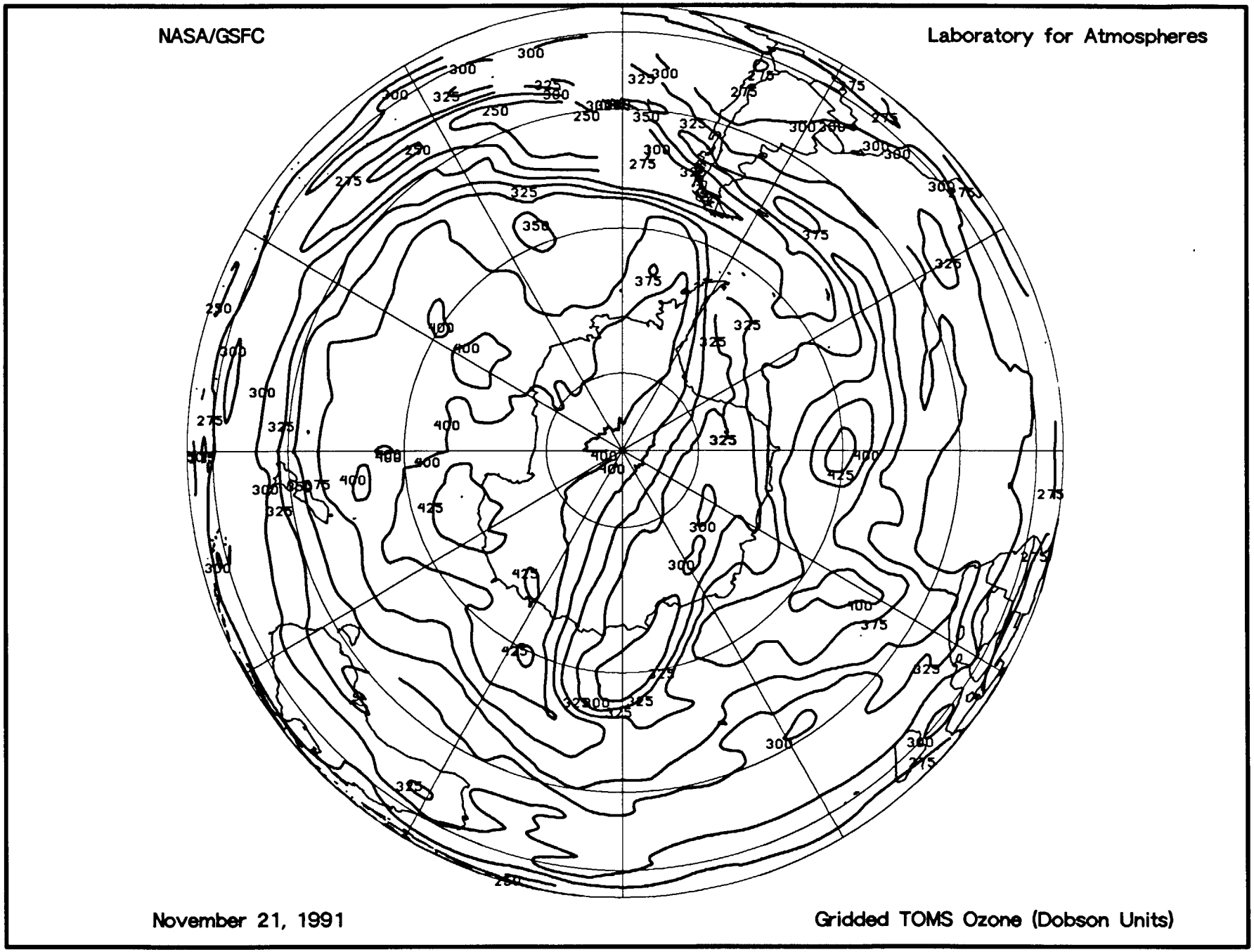
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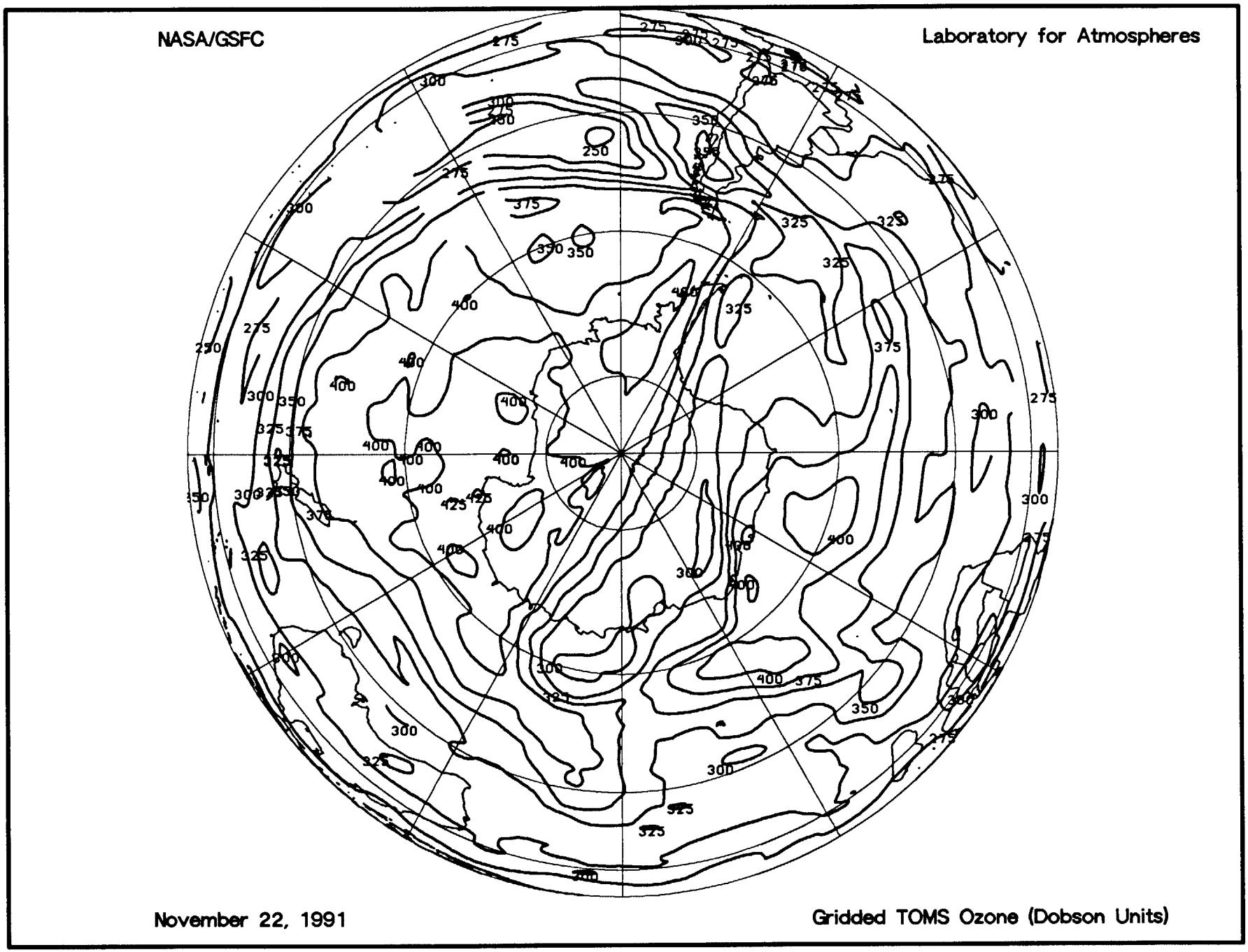
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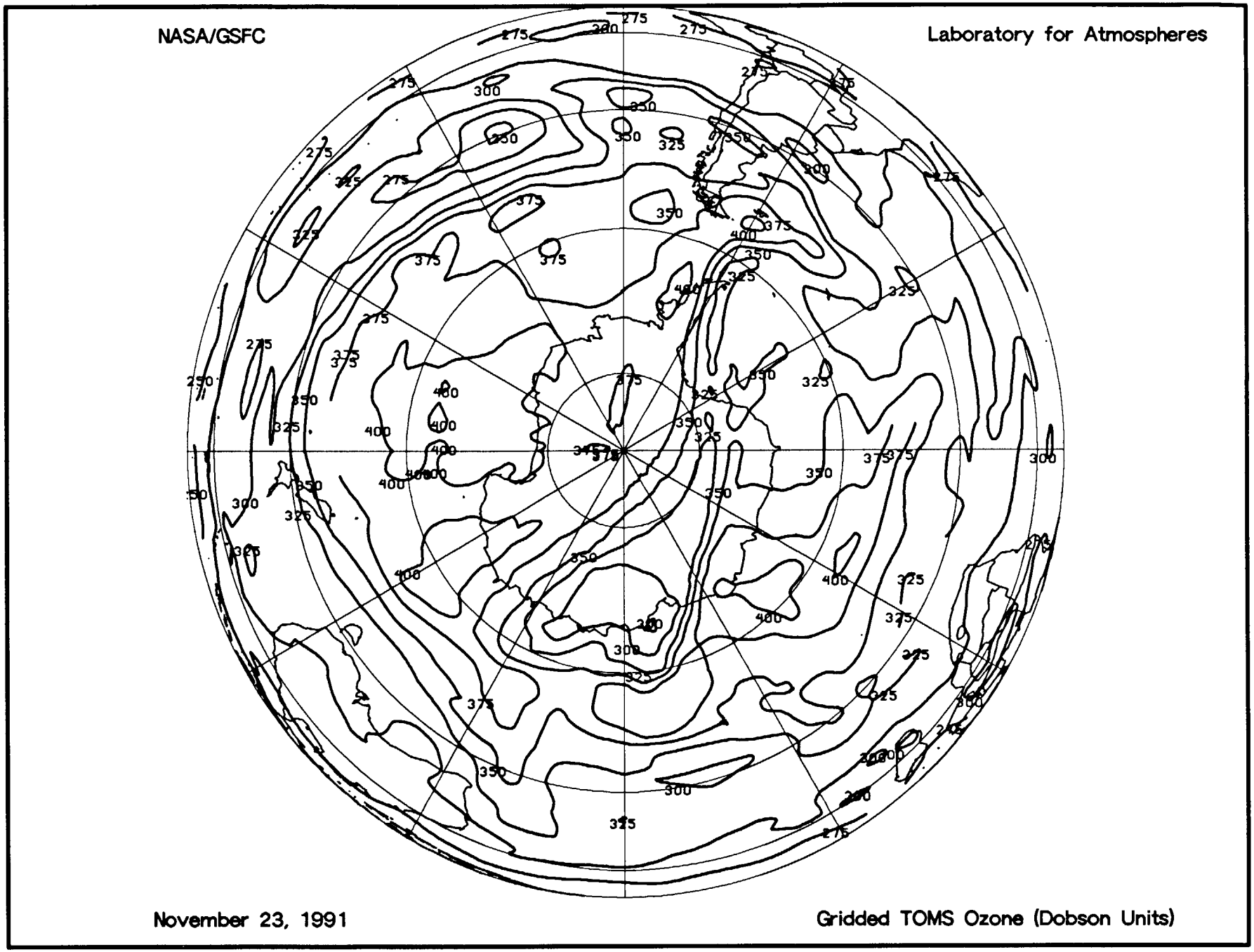
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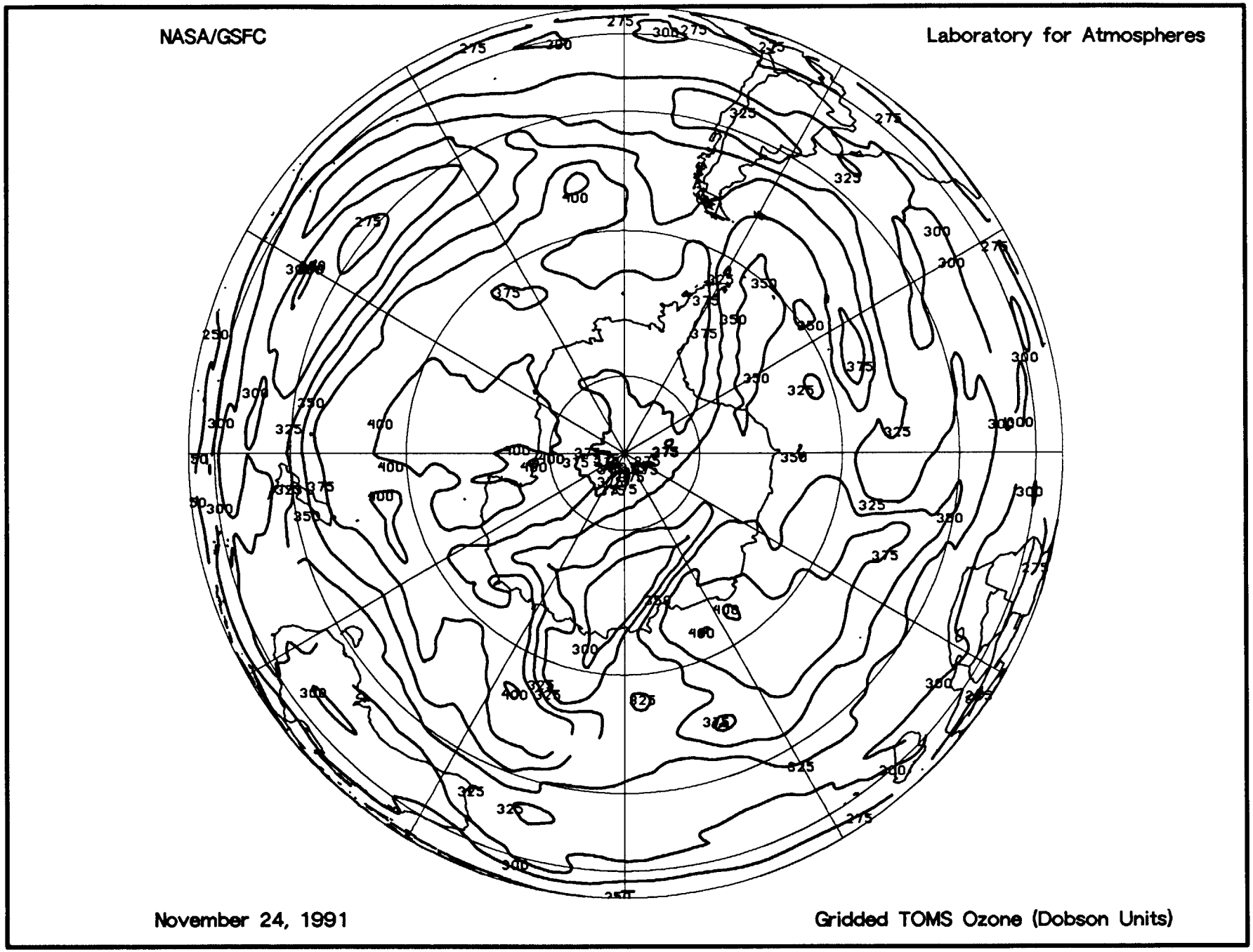
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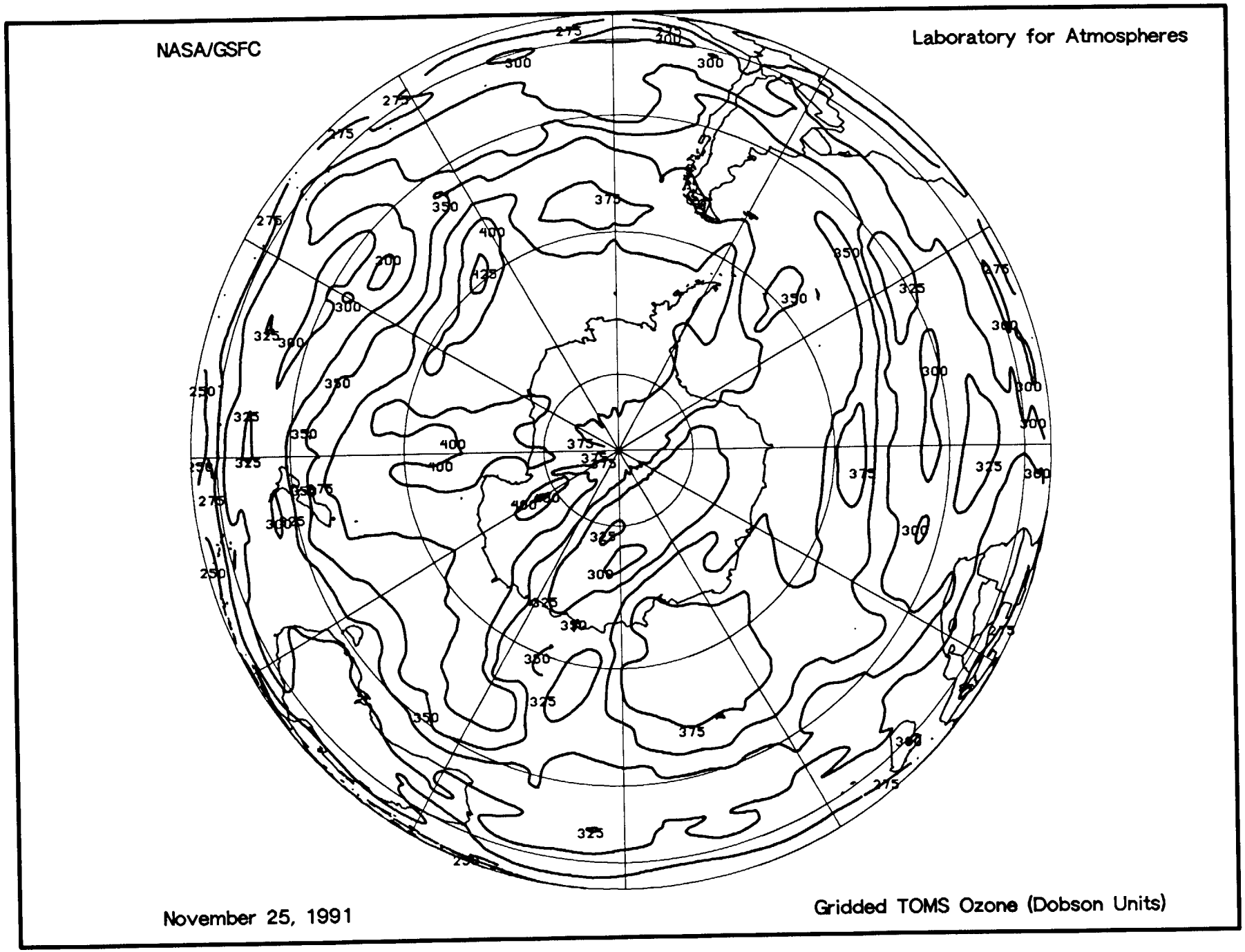
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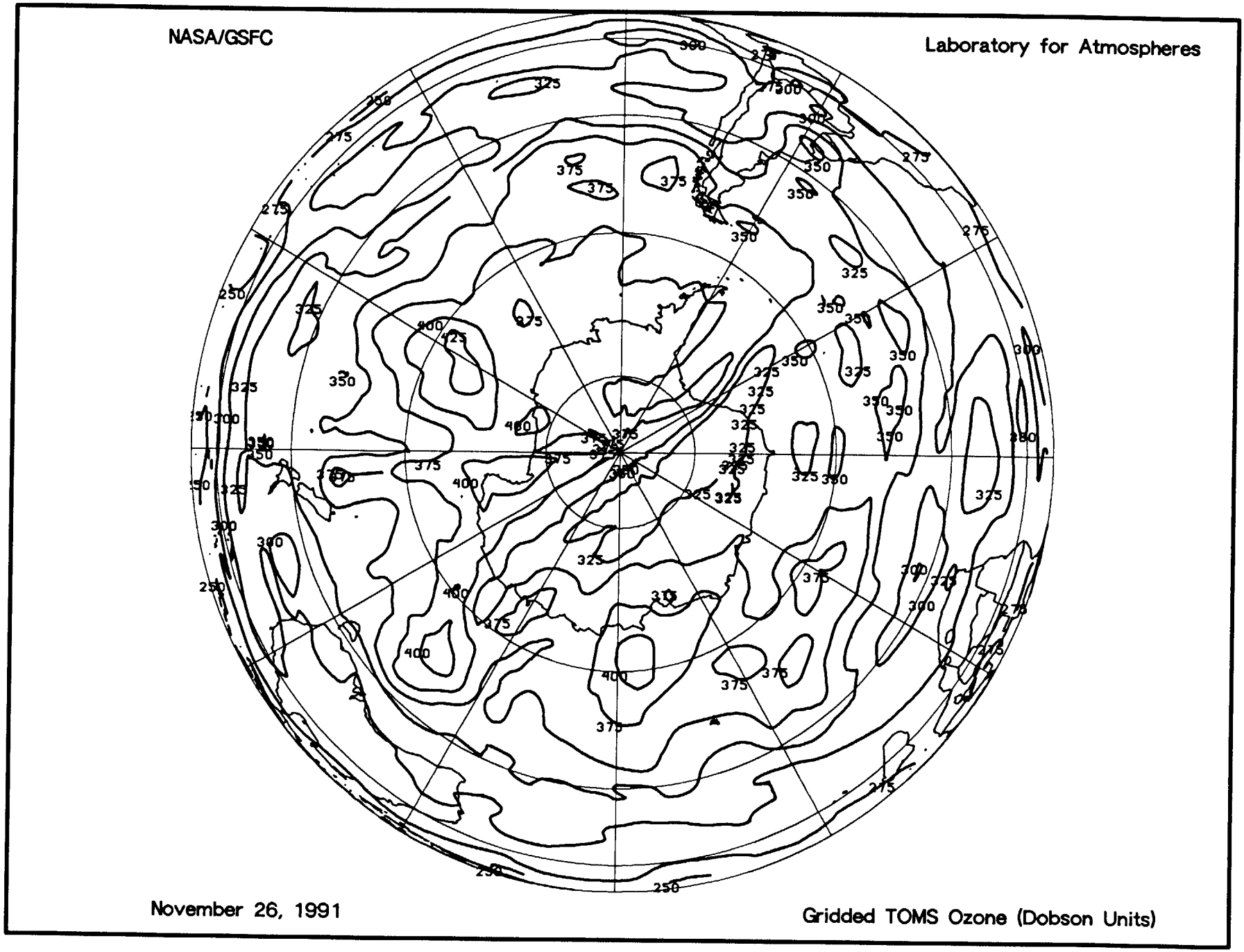
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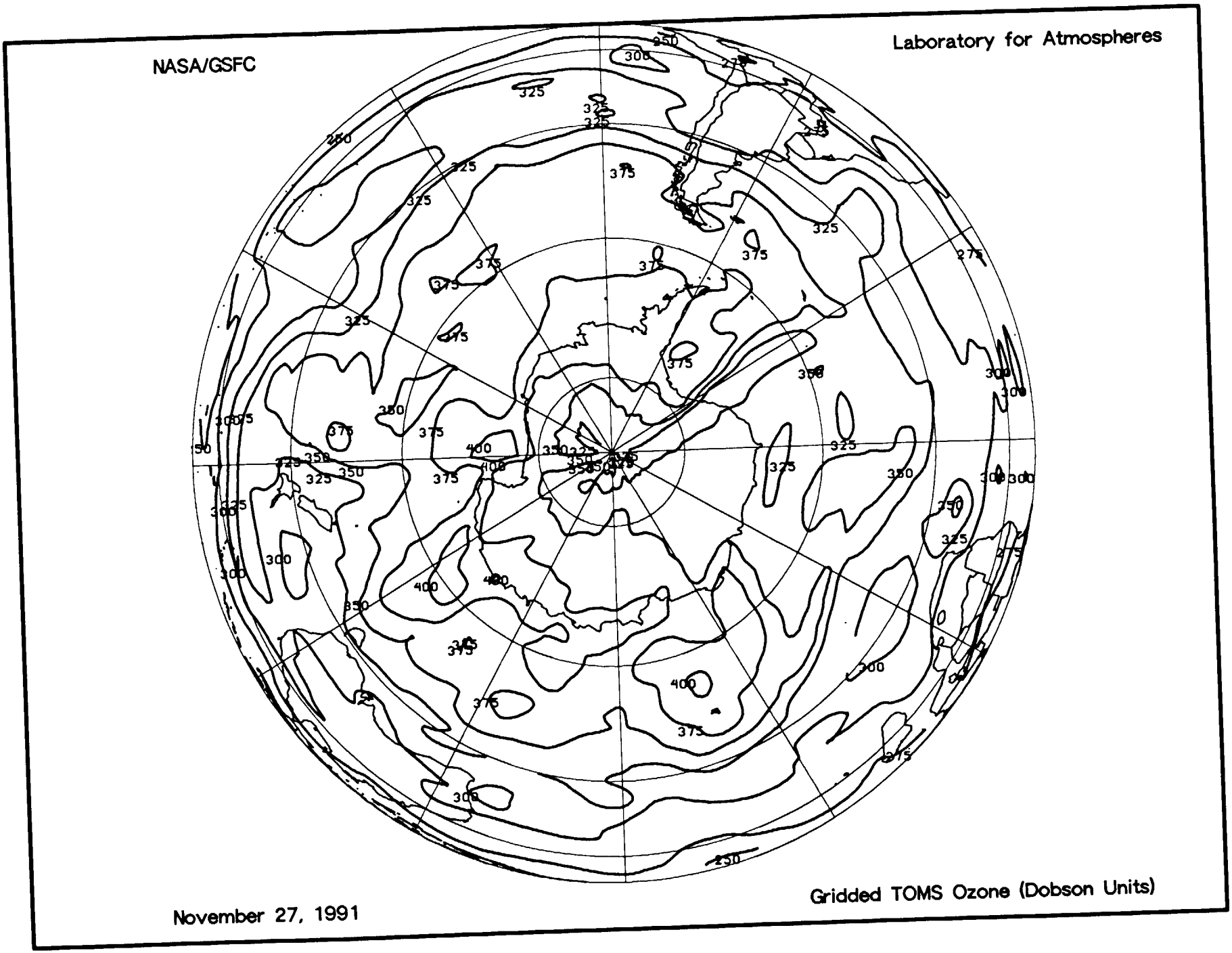
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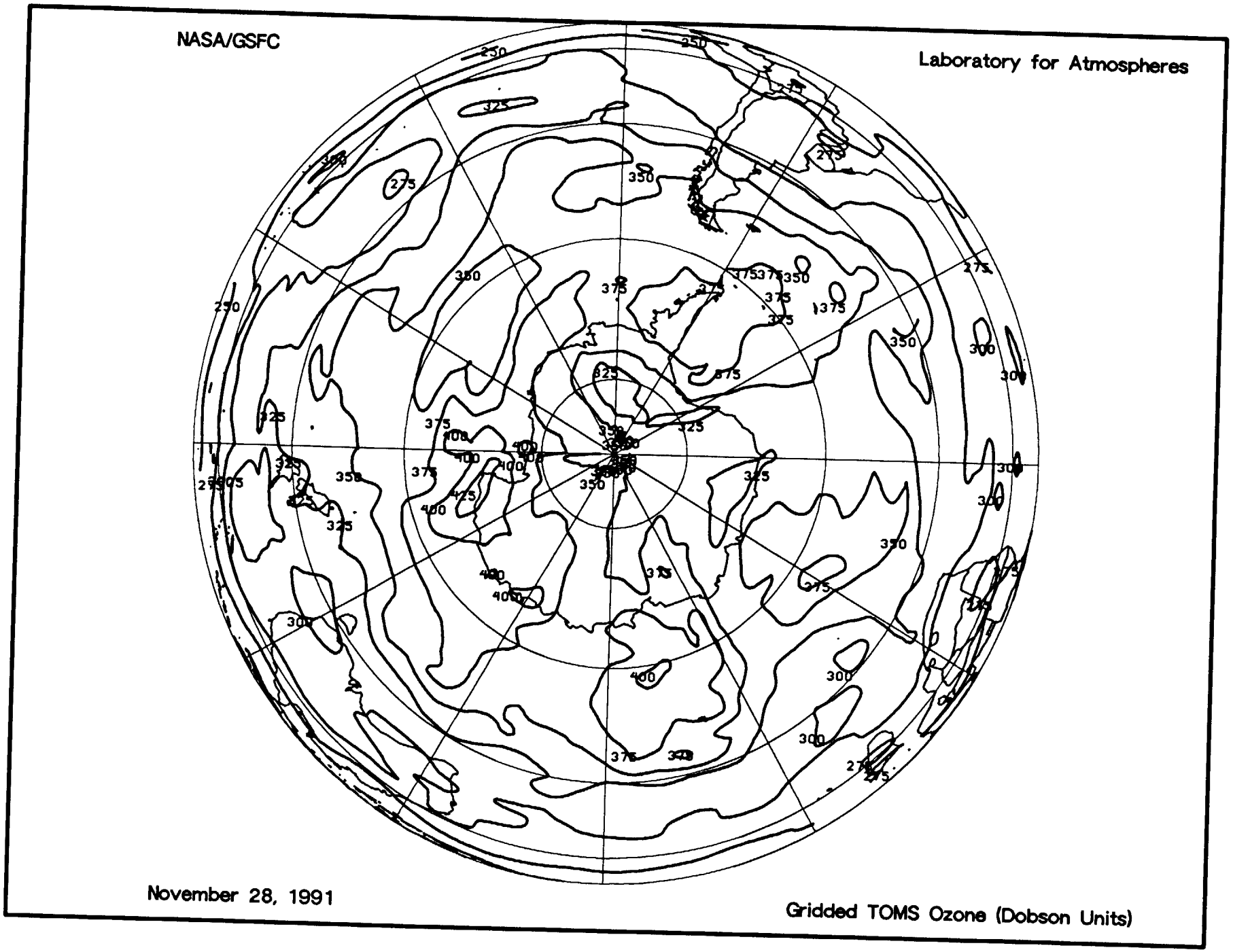
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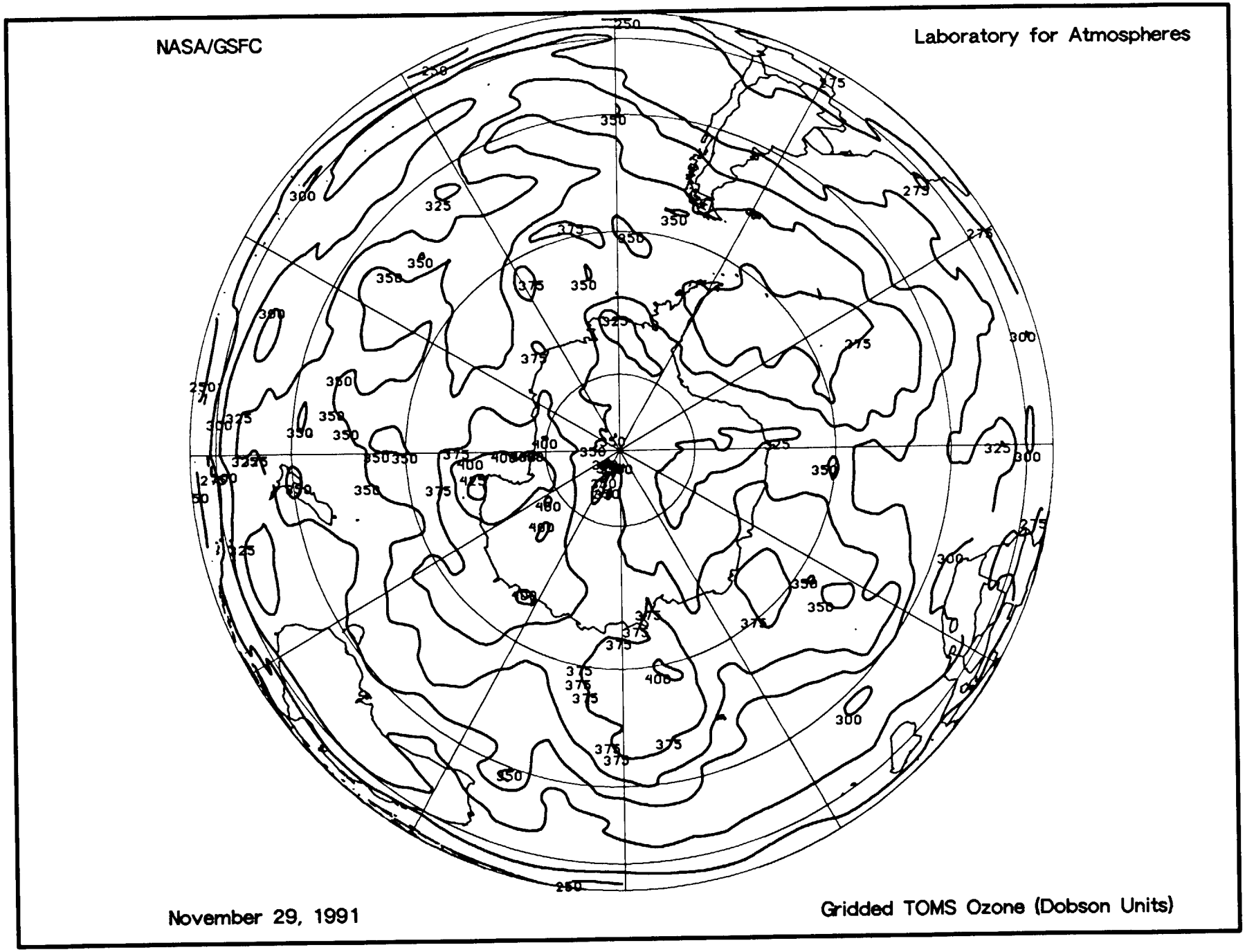
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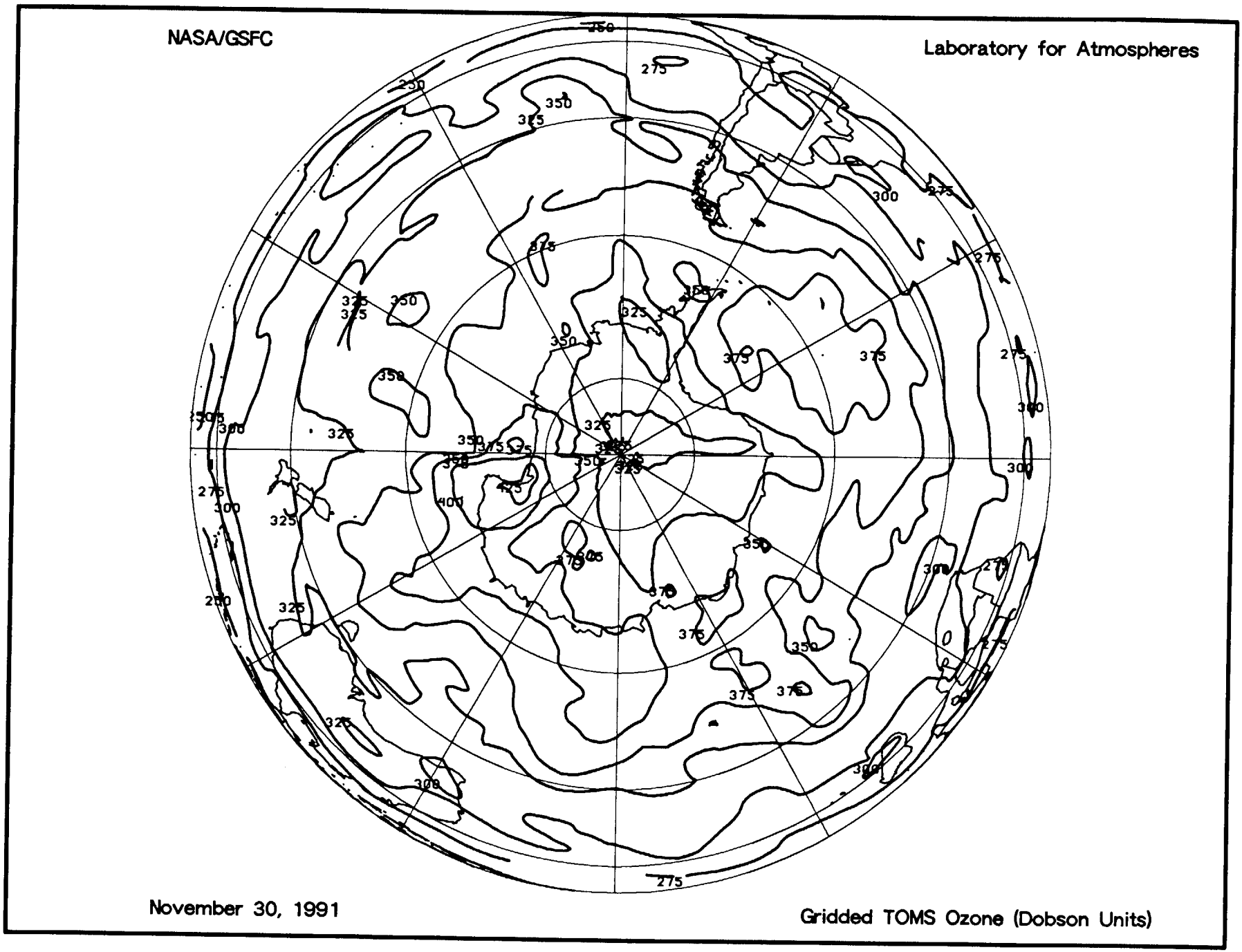
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November 30, 1991
Gridded TOMS Ozone (Dobson Units)

2.3 Time Series at Locations of Interest

2.3.1 Daily Time Series for 1991

Time series of TOMS total ozone estimates have been constructed for a set of twelve locations in Antarctica and two in South America. A list of the selected stations, their abbreviations, their coordinates, and the coordinates of the center of the grid data cell within which the station lies is provided in Table 1. The time series incorporate daily gridded measurements from the southern hemispheric grids (Section 2.2) and are extracted from the 2° (latitude) by 5° (longitude) grid element within which each station lies. At the mean latitude of 70°S, this corresponds to a spatial average over an area 222 km by 189 km. Table 2 presents the time series for the period August 1 through November 30, 1991. Of course, a number of stations are located south of the Antarctic Circle, and experience 24-hour night during a portion of the period. During these periods, the TOMS total ozone estimates at these stations, which include Amundsen-Scott, Halley Bay, McMurdo Sound and Vostok are not available, and are represented by asterisks. Table 3 presents monthly mean total ozone for all of the stations over the entire record of Nimbus-7 TOMS observations.

Amundsen-Scott (SPO)

The Amundsen-Scott station is located at 90°S at the South Pole. At this extreme location, total ozone observations do not become available until September 26 (day 269), shortly after the spring equinox. Total ozone values decline (Figure 1A), reaching a minimum of 115 DU on October 5 (day 278). Values rise quickly to 150 to 160 DU and remain rather steady until October 24 (day 297). A fairly steady rise follows. Total ozone values rise dramatically in late October, over 200 DU in only five days as the filling ozone hole is pushed off the pole and replaced by a strong maximum.

Davis (DAV)

The Davis station is located on the coast of Antarctica at 69°S, 78°E near Mackenzie Bay. A gradual decrease in total ozone (Figure 1B) is observed through September 27 (day 270). A rapid decline follows culminating in a minimum value of 163 DU on October 4 (day 277). A dramatic increase of over 250 DU then follows over the next 2 weeks. Total ozone values are erratic thereafter as the elongated ozone hole rotates into and out of the area.

Dumont D'Urville (DUD)

The Dumont D'Urville station is located at 67°S on the Antarctic coast of Wilkes Land, almost 180° of longitude away from the Antarctic Peninsula. The station remains on the periphery of the ozone hole throughout the period (Figure 1C), only briefly entering the hole when its axis of elongation passes through the area in early October, reaching a minimum value of 169 DU on October 9 (day 282). With the exception of this brief period, the general trend of total ozone over the station is a gradual rise until late October, with a gradual decline thereafter.

Faraday Station (FAR)

The Faraday station is located at 65°S on the Antarctic Peninsula (Figure 1D). A gradual and erratic decline in total ozone results in minimum values on October 8 (day 281). Values remain generally below 200 DU until a dramatic one-day rise of over 100 DU on October 31 (day 304). Total ozone values generally remain above 300 DU thereafter.

Halley Bay (HAL)

The total ozone measurements over Halley Bay at 76°S on the Weddell Sea first become available on August 20 (day 232). The station quickly comes under the influence of the ozone hole, reaching a minimum total ozone value of 143 DU on September 30 (day 273) (Figure 1E). The station remains within the ozone hole until early November, when total ozone values rise quickly.

Maitri (MAT)

The Maitri station is located at 70°S on the coast of Queen Maude Land. The station experiences a steady decline in total ozone (Figure 1F), reaching a minimum value of 173 DU on September 29 (day 272). A brief, but dramatic rise to over 350 DU follows quickly as a maximum over the South Atlantic builds into the region. However, for most on the latter half of October and the first half of November, the ozone hole is deflected off the pole toward this area. As a result, total ozone values remain low, often below 200 DU until mid-November, when they rise quickly as the ozone hole dissipates.

B.A. Vice Comodoro Marambio (MAR)

The Marambio station is located at 64°S, just off the tip of the Antarctic Peninsula. A gradual but erratic decline in total ozone values (Figure 1G) continues until a minimum of 157 DU is reached on October 9 (day 282). Values generally remain below 200 DU until a dramatic rise of nearly 150 DU in two days commences on October 31 (day 304). Thereafter, total ozone values remain above 300 DU.

McMurdo (MCM)

The McMurdo station is located at 78°S on McMurdo Sound near the dateline. Total ozone measurements first become available on August 27 (day 239). A gradual but very erratic decline in total ozone (Figure 1H) results in a minimum value of 150 DU on October 10 and 11 (day 283 and 284). This is followed by a rapid and remarkably steady rise through mid-November.

Molodeznaya (MOL)

The Molodeznaya station is located in coastal Antarctica at 68°S in eastern Queen Maude Land. Total Ozone values decline steadily (Figure 1I), reaching a minimum value of 183 DU on September 30 (day 273). Elongation of the ozone hole causes a dramatic rise to 450 DU by October 10 (day 283). Thereafter, a steady decline occurs, reaching a second minimum of 212

DU on November 8 (day 312) as the filling ozone hole is deflected over the station. A steady rise follows as the ozone hole dissipates.

Palmer Station (PAL)

The Palmer station (Figure 1J) and Farraday station lie within adjacent grid elements and display the same ozone trends.

Punta Arenas (PUN)

Punta Arenas, located near Cape Horn in extreme southern Chile at 53°S, is one of two populous areas of this analysis. The station remains on the fringe of the ozone hole throughout the period (Figure 1K). However, on six occasions, the elongated ozone hole approaches the area resulting in six minima of between 200 and 240 DU. These minima occur at remarkably constant intervals of approximately two weeks, from early August through late October. Thereafter, only once, in mid-November, does the now filling ozone hole approach the area. The October 1991 monthly mean is the lowest ever observed at this location due to the periodic encroachment of the ozone hole.

Syowa (SYO)

Syowa is located at 69°S, quite close to Molodeznaya. As such, the two time series are highly correlated (Figure 1L).

Ushuaia (USH)

Ushuaia is located at 54°S, 68°W in Argentina. The total ozone observations (Figure 1M) are well correlated with those of Punta Arenas.

Vostok (VOS)

The Vostok station is located deep within continental Antarctica at 78°S in southern Wilkes Land. Total ozone values first become available on August 26 (day 238). A gradual and erratic decline in total ozone (Figure 1N) results in a minimum value of 132 DU on October 6 (day 279). A fairly steady rise continues until mid-November, as the station, for the most part lies only on the periphery of the deflected ozone hole.

2.3.2 Monthly Time Series for 13 Years

Table 3 presents monthly mean total ozone values for the fourteen stations for the entire 13-year Nimbus-7 TOMS record.

Amundsen-Scott

At the South Pole, total ozone values are not available from April through August. Minimum values occur in September and October, and have declined rather unsteadily over the period. The absolute lowest means occurring in 1987 and 1991. Maximum total ozone values generally

occur from November through January. These values have declined over the years in a similar fashion. An irregular decline for all 7 months is apparent at this station.

Davis

The lowest mean total ozone values at Davis (69°S) occur in August and September. While only one monthly mean below 300 DU occurred during the first 3 years of the record, an average of 5 such months has occurred during each of the past 3 years. The lowest monthly mean occurred in September of 1990. Total ozone maxima above 400 DU have occurred during only 2 years, 1979 and 1988. Again an unsteady decline is apparent for virtually all months.

Dumont D'Urville

Prior to 1983, the lowest monthly mean total ozone values at Dumont D'Urville (67°S) occurred during April and May. However, recently, as the ozone hole has expanded further north, annual minima have moved to August and September. The progressive decline in monthly mean values over the years is only weakly apparent here.

Faraday/Palmer

These stations are located at 65°S on the Antarctic Peninsula. The annual pattern shows dual total ozone minima, April/May, and September/October. Recently, very low monthly means have occurred in August as well, perhaps due to the many strong mini-holes which seem to frequent this area. A rather steady decline over the years, especially for the period April through October is apparent.

Halley Bay

Over Halley Bay, at 76°S, a dramatic decline in the monthly means for August, September and October has occurred over the years. Also of interest is the accelerated decline of the April monthly means, perhaps suggesting some ozone depletion with the waning sunlight available prior to the antarctic night. A decided December annual maximum has also declined over the period of study.

Maitri

At Maitri (70°S), monthly means have eroded significantly over the 13-year period, especially for the months of August through November.

Marambio

Over the Marambio station, at 64°S, a steady decline has occurred for all months, most pronounced during August, September and October.

McMurdo

At 78°S, over McMurdo, while the serious decline in total ozone is apparent for August, September and October, there is little indication of the decline in either April or November seen at some other stations.

Molodeznaya/Syowa

At Molodeznaya, at 68°S, the maximum monthly mean during this period occurs in October of 1979. The lowest occurs in October of 1987, a rather significant shift in the annual pattern. A strong decline is apparent, not only during the ozone hole period of August though November, but also during May and July.

Punta Arenas/Ushuaia

While a very irregular and small decline in total ozone can be seen over these inhabited areas for all months, it seems pronounced only for the month of October. Due to the influence of the ozone hole during the month of October, a time of near maximum annual total ozone early in the period has become a minimum lately.

Vostok

Over Vostok, at 78°S, significant declines in monthly total ozone are confined to the ozone hole months of August, September and October.

Table 1
Selected Locations for TOMS Total Ozone Time Series

Station Name	Location		Center of Cell	
	Latitude	Longitude	Latitude	Longitude
Amundsen-Scott (SPO)	-90.0	0.0	-90.0	0.0
Davis (DAV)	-68.6	78.0	-68.0	77.5
Dumont D'Urville (DUD)	-66.7	140.0	-66.0	137.5
Faraday Station (FAR)	-65.3	-64.3	-66.0	-62.5
Halley Bay (HAL)	-75.5	-26.7	-76.0	-27.5
Maitri (MAT)	-70.0	12.5	-70.0	12.5
Marambio (MAR)	-64.2	-56.7	-64.0	-57.5
McMurdo (MCM)	-77.9	166.7	-78.0	167.5
Molodeznaya (MOL)	-67.7	45.9	-68.0	47.5
Palmer Station (PAL)	-64.8	-64.0	-64.0	-62.5
Punta Arenas (PUN)	-53.0	-70.9	-52.0	-72.5
Syowa (SYO)	-69.0	39.6	-68.0	37.5
Ushuaia (USH)	-54.9	-68.3	-54.0	-67.5
Vostok (VOS)	-78.5	106.9	-78.0	107.5

Table 2
Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	DAV	DUD	FAR	HAL	MAT	MAR	MCM	MOL	PAL	PUN	SYO	USH	VOS
213	AUG 1	***	298	246	234	***	289	253	***	316	245	238	309	254	***
214	AUG 2	***	294	227	239	***	293	241	***	315	251	223	306	212	***
215	AUG 3	***	349	228	278	***	263	281	***	301	281	264	295	251	***
216	AUG 4	***	290	235	258	***	260	274	***	297	262	297	299	297	***
217	AUG 5	***	296	249	241	***	266	257	***	266	245	336	267	324	***
218	AUG 6	***	276	243	231	***	261	239	***	261	243	349	260	335	***
219	AUG 7	***	280	230	220	***	264	233	***	269	239	293	277	293	***
220	AUG 8	***	290	250	222	***	260	231	***	273	251	318	264	314	***
221	AUG 9	***	286	257	235	***	258	235	***	260	238	330	274	312	***
222	AUG 10	***	287	294	239	***	225	233	***	281	242	326	266	305	***
223	AUG 11	***	301	319	255	***	217	261	***	249	252	350	244	323	***
224	AUG 12	***	265	311	198	***	223	218	***	238	234	334	233	311	***
225	AUG 13	***	242	307	224	***	265	244	***	252	246	328	251	330	***
226	AUG 14	***	258	279	233	***	268	246	***	261	242	297	247	284	***
227	AUG 15	***	259	288	237	***	243	251	***	222	253	360	225	339	***
228	AUG 16	***	206	287	264	***	255	273	***	219	274	253	242	288	***
229	AUG 17	***	222	267	236	***	229	229	***	257	231	234	255	244	***
230	AUG 18	***	239	298	253	***	243	246	***	233	253	345	231	335	***
231	AUG 19	***	238	270	253	***	269	269	***	240	265	317	261	308	***
232	AUG 20	***	255	230	211	234	219	222	***	275	217	298	264	283	***
233	AUG 21	***	243	270	212	225	231	225	***	239	224	324	237	306	***
234	AUG 22	***	240	257	236	215	238	247	***	240	250	298	234	303	***
235	AUG 23	***	253	252	207	221	249	229	***	252	236	273	254	269	***
236	AUG 24	***	236	239	205	189	239	214	***	240	228	292	247	282	***
237	AUG 25	***	263	228	245	197	242	270	***	241	264	326	237	319	***
238	AUG 26	***	239	248	260	212	236	256	***	266	261	335	256	336	230
239	AUG 27	***	248	251	271	246	213	275	222	249	279	395	237	398	215
240	AUG 28	***	251	251	260	251	235	268	179	247	265	406	238	390	212
241	AUG 29	***	249	298	226	235	217	240	209	255	232	399	247	371	199
242	AUG 30	***	262	314	180	243	237	202	219	226	195	311	221	296	220
243	AUG 31	***	262	317	200	188	257	193	228	230	203	230	234	232	215
244	SEP 1	***	268	235	225	199	257	214	237	280	222	262	282	239	227
245	SEP 2	***	312	289	273	194	205	259	235	269	274	266	253	259	255
246	SEP 3	***	264	405	201	183	196	249	259	219	242	275	215	272	238
247	SEP 4	***	249	464	191	218	212	197	229	217	200	294	206	283	226
248	SEP 5	***	245	469	214	219	218	232	255	218	224	314	215	308	240

Table 2 (continued)
Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	DAV	DUD	FAR	HAL	MAT	MAR	MCM	MOL	PAL	PUN	SYO	USH	VOS
249	SEP 6	***	223	385	228	173	230	234	238	210	229	299	231	284	208
250	SEP 7	***	228	313	211	183	233	215	221	232	210	280	233	263	204
251	SEP 8	***	246	347	206	186	239	211	209	247	204	298	237	291	207
252	SEP 9	***	284	278	191	191	230	199	226	233	194	286	224	294	210
253	SEP 10	***	294	267	187	184	244	181	204	238	186	262	232	248	185
254	SEP 11	***	288	304	240	187	235	235	191	243	261	346	236	326	184
255	SEP 12	***	286	315	285	183	195	314	184	250	311	375	244	360	209
256	SEP 13	***	298	386	265	185	200	284	204	246	290	407	223	406	244
257	SEP 14	***	289	456	265	175	225	296	256	226	294	341	214	343	285
258	SEP 15	***	289	473	227	172	185	259	293	216	244	338	203	332	242
259	SEP 16	***	266	480	211	172	178	228	298	211	215	295	211	299	259
260	SEP 17	***	230	471	196	175	183	227	340	208	217	282	206	281	233
261	SEP 18	***	205	458	181	169	209	213	281	212	196	272	214	278	194
262	SEP 19	***	231	398	175	188	201	187	235	206	185	280	204	278	167
263	SEP 20	***	225	281	185	191	207	194	207	203	193	264	203	264	168
264	SEP 21	***	223	304	184	178	214	192	186	217	189	228	228	210	165
265	SEP 22	***	250	301	181	177	233	180	177	241	182	286	250	264	165
266	SEP 23	***	265	308	197	173	238	214	177	265	204	269	271	246	184
267	SEP 24	***	309	355	172	162	218	188	186	320	183	319	320	316	194
268	SEP 25	***	368	338	173	178	200	198	173	348	201	310	313	324	215
269	SEP 26	145	383	384	188	172	200	194	170	275	208	332	244	340	250
270	SEP 27	141	306	396	231	168	198	241	194	219	263	349	212	324	241
271	SEP 28	140	251	430	255	159	181	265	198	206	267	331	202	318	202
272	SEP 29	134	233	406	218	151	173	230	189	205	229	332	193	327	183
273	SEP 30	133	215	331	171	143	175	182	187	183	173	343	171	312	173
274	OCT 1	131	189	396	172	156	175	179	194	195	176	294	197	271	166
275	OCT 2	132	199	376	178	150	178	187	207	212	180	281	214	265	163
276	OCT 3	140	188	370	181	165	210	192	273	192	179	258	191	238	154
277	OCT 4	126	163	353	157	153	250	165	212	199	153	217	226	210	141
278	OCT 5	115	172	375	189	156	272	179	192	227	194	230	263	226	139
279	OCT 6	119	188	326	184	160	290	202	206	273	188	231	319	229	132
280	OCT 7	123	214	198	163	174	348	182	203	361	173	244	393	241	135
281	OCT 8	130	297	175	155	181	365	167	182	427	148	245	438	238	142
282	OCT 9	140	372	169	156	186	356	157	162	425	149	248	420	198	152
283	OCT 10	149	355	195	197	179	357	167	150	449	191	305	435	299	164
284	OCT 11	154	392	264	167	170	322	177	150	444	173	358	425	308	192

Table 2 (continued)
Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	DAV	DUD	FAR	HAL	MAT	MAR	MCM	MOL	PAL	PUN	SYO	USH	VOS
285	OCT 12	151	431	260	170	160	270	176	158	430	175	383	409	334	212
286	OCT 13	143	436	291	181	155	255	196	159	397	191	361	372	336	219
287	OCT 14	142	437	336	204	156	243	215	158	367	208	266	342	278	219
288	OCT 15	154	393	382	185	151	229	185	172	353	189	289	328	262	236
289	OCT 16	160	425	398	178	151	230	196	192	395	204	305	364	277	235
290	OCT 17	158	446	370	177	161	220	203	196	384	200	324	344	294	247
291	OCT 18	158	425	452	178	154	189	185	216	367	177	314	310	292	264
292	OCT 19	156	416	469	204	175	194	207	224	261	201	259	230	247	268
293	OCT 20	152	242	479	177	187	271	192	273	282	176	270	303	262	221
294	OCT 21	153	319	467	168	170	248	181	258	351	181	262	336	245	201
295	OCT 22	153	360	410	176	174	230	187	255	319	177	242	294	239	210
296	OCT 23	158	355	443	171	178	226	171	241	315	170	209	294	196	216
297	OCT 24	165	339	435	177	172	262	177	250	300	168	230	327	211	208
298	OCT 25	169	385	473	187	172	285	187	204	347	192	269	353	244	227
299	OCT 26	179	395	513	197	173	263	199	259	387	197	259	360	251	283
300	OCT 27	190	424	459	190	178	279	196	293	377	192	259	361	237	301
301	OCT 28	208	411	486	196	178	239	193	329	350	207	267	319	251	328
302	OCT 29	210	349	486	193	181	207	193	357	299	204	252	273	245	322
303	OCT 30	216	347	490	217	185	193	213	359	272	225	278	243	245	283
304	OCT 31	207	320	475	327	177	205	307	327	262	333	335	250	320	244
305	NOV 1	195	280	473	338	183	195	358	317	243	375	366	234	348	239
306	NOV 2	189	379	460	341	176	208	342	245	289	362	392	261	389	204
307	NOV 3	212	367	433	353	184	198	352	318	282	372	378	249	369	285
308	NOV 4	222	375	465	374	182	197	380	328	267	397	382	231	389	305
309	NOV 5	225	382	457	347	192	189	366	361	242	377	374	227	394	328
310	NOV 6	229	353	478	364	187	184	350	381	240	362	344	215	352	340
311	NOV 7	268	299	450	359	187	193	363	385	224	372	368	211	373	328
312	NOV 8	268	267	432	398	212	194	382	380	212	395	369	208	371	313
313	NOV 9	255	237	443	392	236	191	398	374	219	405	359	217	371	270
314	NOV 10	217	321	426	387	248	199	374	359	229	381	354	212	349	214
315	NOV 11	192	379	431	386	274	211	388	241	251	389	376	222	368	291
316	NOV 12	199	402	418	349	286	223	371	318	261	367	372	226	369	370
317	NOV 13	242	407	432	292	253	277	354	391	266	328	368	236	367	407
318	NOV 14	298	370	450	294	216	255	376	431	253	360	371	238	378	417
319	NOV 15	334	356	430	312	214	224	383	429	234	363	376	235	369	392
320	NOV 16	362	362	407	304	218	226	339	419	257	319	372	240	379	414

Table 2 (continued)
Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	DAV	DUD	FAR	HAL	MAT	MAR	MCM	MOL	PAL	PUN	SYO	USH	VOS
321	NOV 17	402	352	434	296	267	258	308	431	306	293	347	272	354	404
322	NOV 18	405	316	449	297	302	322	314	425	306	301	312	302	327	395
323	NOV 19	408	305	459	312	330	334	323	437	320	317	286	334	301	367
324	NOV 20	414	298	439	341	334	325	317	428	365	326	295	358	288	379
325	NOV 21	398	292	421	377	327	358	329	415	355	361	295	334	294	366
326	NOV 22	390	300	414	384	314	377	347	411	380	385	320	394	381	363
327	NOV 23	387	292	390	384	328	344	321	397	398	375	356	392	371	350
328	NOV 24	370	376	381	394	353	343	343	391	374	385	334	360	358	332
329	NOV 25	370	378	397	383	361	345	378	387	360	375	356	356	351	323
330	NOV 26	370	372	351	379	365	337	366	403	358	373	363	343	356	330
331	NOV 27	341	377	402	383	343	336	367	367	370	376	345	339	351	351
332	NOV 28	350	367	400	388	331	331	380	387	332	379	355	353	358	365
333	NOV 29	348	367	392	378	338	346	373	406	366	371	348	362	346	358
334	NOV 30	329	354	389	346	344	354	356	431	377	352	353	358	356	370
335	DEC 1	340	362	391	347	338	348	358	401	351	350	333	356	342	359
336	DEC 2	340	362	360	340	345	341	340	388	352	351	345	346	337	361
337	DEC 3	324	340	361	363	350	344	358	385	358	354	348	348	337	357
338	DEC 4	320	344	361	346	347	344	347	357	352	344	365	348	357	346
339	DEC 5	319	339	370	341	345	365	344	343	345	339	370	344	364	350
340	DEC 6	320	348	373	341	344	349	344	337	355	336	373	338	365	350
341	DEC 7	317	352	351	338	335	339	336	326	346	335	371	343	368	351
342	DEC 8	317	350	345	343	331	354	353	325	353	344	355	362	343	359
343	DEC 9	314	359	356	331	330	373	333	319	365	337	333	362	336	343
344	DEC 10	310	346	345	331	314	370	331	328	372	336	338	362	337	333
345	DEC 11	314	349	345	346	338	367	333	334	369	347	332	371	326	334
346	DEC 12	326	330	337	331	340	364	330	331	365	334	344	371	344	328
347	DEC 13	337	342	340	362	334	361	342	327	360	360	338	370	345	328
348	DEC 14	341	341	345	357	338	357	347	327	353	362	354	355	351	322
349	DEC 15	338	342	350	353	331	352	355	331	346	360	350	351	353	322
350	DEC 16	329	347	359	349	330	349	350	327	346	353	354	354	358	324
351	DEC 17	326	347	343	348	332	348	358	327	348	351	358	349	369	325
352	DEC 18	328	357	341	344	333	342	348	322	353	344	364	354	373	330
353	DEC 19	323	357	338	347	344	352	353	321	359	355	362	351	371	333
354	DEC 20	321	350	354	350	346	348	354	334	348	357	361	355	364	328
355	DEC 21	317	331	357	372	348	356	376	319	365	376	355	358	352	314
356	DEC 22	314	330	350	375	344	351	379	318	348	375	379	346	374	311

Table 2 (continued)
Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	DAV	DUD	FAR	HAL	MAT	MAR	MCM	MOL	PAL	PUN	SYO	USH	VOS
357	DEC 23	304	319	362	384	336	349	383	316	335	379	367	337	374	323
358	DEC 24	300	324	360	384	330	341	376	317	299	385	368	308	374	333
359	DEC 25	309	328	366	373	333	341	368	309	310	372	352	309	369	316
360	DEC 26	307	332	370	365	330	346	365	314	283	367	343	297	353	316
361	DEC 27	302	334	366	363	332	318	367	315	305	364	339	305	348	322
362	DEC 28	298	344	348	359	331	309	363	309	316	363	348	300	349	323
363	DEC 29	299	339	348	358	318	313	355	310	310	352	363	307	362	314
364	DEC 30	297	332	322	351	312	317	346	313	318	351	374	313	369	309
365	DEC 31	295	334	325	350	305	316	346	318	316	348	342	317	342	311

Table 3
Monthly Mean Comparisons

Amundsen-Scott

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	312	329	312	309	317	312	294	286	296	291	293	302	286
February	285	301	281	281	298	286	275	267	291	273	266	267	265
March	292	295	244	270	271	266	241	224	258	282	242	246	240
April	***	***	***	***	***	***	***	***	***	***	***	***	***
May	***	***	***	***	***	***	***	***	***	***	***	***	***
June	***	***	***	***	***	***	***	***	***	***	***	***	***
July	***	***	***	***	***	***	***	***	***	***	***	***	***
August	***	***	***	***	***	***	***	***	***	***	***	***	***
September	260	228	257	224	202	191	174	189	140	216	161	175	139
October	299	231	236	247	196	202	172	189	146	241	159	150	156
November	357	320	311	263	325	279	245	331	189	363	249	192	306
December	367	348	355	346	339	304	324	330	325	343	323	287	318

Davis

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	324	353	344	345	341	336	321	309	320	319	335	317	327
February	336	345	317	337	336	326	311	296	326	325	323	311	306
March	320	345	325	305	314	315	302	292	315	303	299	298	297
April	326	347	322	323	321	296	285	278	310	284	300	287	311
May	310	360	312	308	300	311	292	312	283	291	301	311	286
June	***	***	***	***	***	***	***	***	***	***	***	***	***
July	331	314	341	326	301	289	297	318	292	307	297	276	274
August	319	314	314	298	306	289	291	275	261	328	262	248	264
September	326	294	348	305	300	297	238	280	234	407	234	223	267
October	453	363	366	279	310	321	250	297	241	403	280	270	335
November	391	403	391	374	354	373	287	357	296	395	309	300	343
December	380	378	361	349	355	346	310	351	345	361	346	334	342

Table 3 (continued)
Monthly Mean Comparisons

Dumont D'Urville

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	359	360	353	343	337	321	318	312	317	325	336	323	322
February	340	360	339	342	332	335	326	288	328	338	329	326	323
March	329	339	339	340	325	327	336	303	325	325	318	308	315
April	330	328	351	331	337	319	306	313	312	308	308	298	320
May	324	371	334	299	324	303	312	294	305	296	331	303	315
June	341	372	307	312	323	344	322	379	294	307	337	342	279
July	342	332	328	311	339	326	313	302	297	317	305	286	272
August	334	329	325	312	333	305	318	310	287	359	286	272	266
September	390	333	336	361	300	365	310	356	266	404	272	357	368
October	460	441	404	410	425	402	340	355	325	466	386	315	380
November	425	414	445	385	412	424	389	417	330	431	379	351	427
December	382	378	381	357	353	339	338	363	358	375	344	346	353

Faraday Station

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	334	349	336	323	329	340	326	317	333	320	327	312	312
February	315	322	327	311	328	314	306	300	300	309	305	300	299
March	298	301	293	308	308	286	302	281	306	298	302	292	296
April	299	309	295	316	299	285	312	274	301	289	292	277	262
May	292	303	320	296	300	269	278	272	290	282	286	253	273
June	295	314	313	286	324	279	269	284	296	297	296	269	273
July	324	335	322	320	318	284	283	301	288	269	309	267	265
August	309	310	316	288	302	278	282	304	271	244	274	261	234
September	284	292	281	268	285	254	277	263	236	245	247	219	211
October	327	308	297	308	296	244	271	297	242	239	206	268	186
November	363	320	346	332	346	349	320	329	264	343	355	249	354
December	377	361	363	352	352	340	343	345	311	361	324	278	353

Table 3 (continued)
Monthly Mean Comparisons

Halley Bay

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	315	344	317	315	330	321	311	303	312	308	305	310	300
February	300	306	308	294	314	291	280	284	288	280	295	280	273
March	293	308	290	284	298	296	271	255	281	280	272	267	278
April	285	293	271	279	266	267	270	230	268	267	261	250	237
May	***	***	***	***	***	***	***	***	***	***	***	***	***
June	***	***	***	***	***	***	***	***	***	***	***	***	***
July	***	***	***	***	***	***	***	***	***	***	***	***	***
August	292	304	304	285	266	258	247	264	253	250	236	218	221
September	266	260	274	244	240	221	219	223	188	214	199	186	180
October	296	245	260	233	210	198	194	242	164	229	168	185	168
November	341	311	315	287	305	252	230	294	200	339	274	218	270
December	371	364	361	344	347	332	328	322	310	347	319	270	334

Maitri

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	335	361	324	326	343	337	327	315	323	323	326	333	318
February	327	344	322	328	334	327	300	307	315	306	320	320	313
March	311	338	306	297	300	300	277	282	304	290	290	288	297
April	307	335	288	303	303	285	285	258	297	281	273	274	265
May	290	313	295	296	292	291	288	281	271	277	274	279	252
June	***	***	***	***	***	***	***	***	***	***	***	***	***
July	***	321	***	***	311	279	286	***	280	281	316	238	292
August	324	319	318	289	300	281	270	283	257	299	284	239	247
September	299	285	301	259	283	245	232	233	214	284	224	195	210
October	371	279	314	252	242	239	203	275	190	290	200	234	254
November	373	346	347	341	319	276	240	277	244	350	268	286	269
December	381	379	368	356	359	341	317	324	328	353	339	301	346

Table 3 (continued)
Monthly Mean Comparisons

Marambio

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	331	351	336	323	327	342	324	319	334	324	333	318	311
February	318	332	329	313	331	322	310	308	300	307	306	295	298
March	296	305	299	309	310	288	305	288	305	296	304	294	300
April	298	317	295	310	305	290	317	284	303	295	300	287	270
May	296	306	320	295	303	274	283	277	291	284	283	259	278
June	313	341	322	296	311	283	286	303	291	294	304	284	287
July	324	342	325	328	317	290	291	298	301	271	304	275	273
August	316	320	324	294	305	284	291	313	283	256	281	277	244
September	289	303	290	279	300	264	289	269	249	261	264	228	224
October	336	325	311	305	313	252	278	304	249	252	219	291	191
November	365	334	350	333	342	350	313	323	287	340	359	268	357
December	379	360	359	354	349	337	338	343	308	365	324	282	353

McMurdo

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	341	334	335	329	323	314	310	305	315	314	324	319	307
February	328	337	317	305	308	317	314	281	314	316	305	311	297
March	322	336	304	317	315	302	310	284	303	305	288	287	297
April	278	310	321	301	290	304	275	292	267	293	256	285	271
May	***	***	***	***	***	***	***	***	***	***	***	***	***
June	***	***	***	***	***	***	***	***	***	***	***	***	***
July	***	***	***	***	***	***	***	***	***	***	***	***	***
August	316	317	330	280	300	269	268	276	247	264	266	231	211
September	303	274	284	263	242	243	230	249	201	260	202	229	221
October	379	301	280	340	283	301	239	235	191	332	230	183	226
November	386	373	376	301	389	366	329	391	225	404	303	265	380
December	374	369	374	353	337	346	332	354	349	355	333	315	331

Table 3 (continued)
Monthly Mean Comparisons

Molodeznaya

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	337	366	348	336	350	349	332	316	332	328	333	328	332
February	339	357	323	336	338	327	306	309	320	316	320	322	312
March	303	341	313	299	306	307	288	286	311	289	295	295	304
April	312	350	303	309	309	296	280	268	306	284	290	289	295
May	302	341	298	294	296	303	288	328	267	281	288	296	266
June	***	***	***	***	***	***	***	***	***	***	***	***	***
July	331	324	334	318	308	282	284	317	291	310	298	249	290
August	318	321	314	291	308	284	285	279	256	318	274	247	257
September	321	298	339	281	306	268	235	260	231	357	238	211	235
October	432	317	348	264	274	290	226	303	222	347	243	265	330
November	400	381	361	386	330	329	266	319	282	376	280	305	298
December	379	386	380	362	366	348	310	339	340	362	353	327	342

Palmer Station

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	333	351	334	325	328	342	328	320	334	321	330	316	313
February	319	334	329	315	329	322	309	308	300	310	306	300	301
March	300	303	297	313	312	288	307	287	307	298	306	296	299
April	299	313	299	315	305	292	317	284	305	291	295	282	270
May	295	308	323	299	305	274	280	278	292	282	286	259	276
June	316	341	326	301	314	282	287	306	291	293	305	285	288
July	327	339	327	325	320	295	293	302	303	273	308	278	273
August	316	321	322	296	306	284	289	313	285	254	282	276	245
September	289	305	290	278	296	264	290	276	251	257	263	230	223
October	333	326	308	315	314	251	282	307	255	244	217	286	189
November	365	323	347	333	344	351	320	330	282	339	360	260	363
December	377	356	360	352	350	336	340	344	309	361	324	280	354

Table 3 (continued)
Monthly Mean Comparisons

Punta Arenas

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	324	342	338	329	324	328	321	316	321	323	332	326	307
February	320	337	325	315	316	325	314	314	312	299	300	286	302
March	305	301	302	310	297	288	300	293	282	287	298	293	286
April	288	323	293	283	300	300	315	295	289	290	301	294	294
May	310	323	339	316	313	305	312	294	295	289	292	295	297
June	303	337	306	319	323	301	295	331	294	304	309	296	290
July	339	338	321	336	336	340	297	315	319	293	318	310	315
August	337	348	326	338	319	332	311	335	337	299	334	322	312
September	332	336	347	322	356	329	339	346	319	323	331	309	305
October	375	342	358	360	352	321	336	355	327	306	299	341	276
November	375	335	346	344	342	350	323	350	338	339	363	320	353
December	354	346	343	343	327	327	315	327	315	351	339	296	354

Syowa

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	335	365	337	334	349	351	330	314	329	325	333	332	329
February	338	361	322	337	338	330	306	306	322	315	322	327	311
March	303	344	312	299	307	308	286	289	313	287	295	295	304
April	313	353	305	312	310	296	283	268	307	284	292	288	289
May	299	337	299	300	296	304	286	326	265	280	282	293	261
June	***	***	***	***	***	***	***	***	***	***	***	***	***
July	328	328	340	310	307	286	287	312	286	309	303	250	299
August	326	325	318	291	309	285	285	286	257	318	278	250	255
September	323	300	333	278	309	267	240	258	232	342	242	208	230
October	427	309	347	264	272	280	222	305	216	333	234	264	320
November	400	376	361	383	330	317	264	307	277	370	276	310	284
December	375	385	384	362	363	344	313	335	339	360	356	324	342

Table 3 (continued)
Monthly Mean Comparisons

Ushuaia

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	323	348	339	326	325	332	321	317	325	326	332	327	305
February	320	339	325	313	318	326	314	319	309	300	301	283	299
March	300	302	306	310	296	290	302	293	284	285	300	296	288
April	293	323	298	287	300	303	317	298	290	294	301	298	292
May	308	315	333	311	308	304	311	299	298	289	290	290	294
June	308	342	304	310	326	295	289	326	301	300	307	295	294
July	334	344	316	335	333	334	290	313	316	288	310	303	306
August	338	351	330	331	317	326	314	329	327	296	327	319	305
September	320	340	338	316	352	320	332	332	318	322	326	301	296
October	374	341	358	351	350	308	327	344	317	298	290	338	258
November	382	335	349	344	341	352	322	345	340	339	361	317	358
December	356	349	347	345	328	328	318	330	310	353	336	291	355

Vostok

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	320	336	327	323	322	312	305	295	310	303	324	308	307
February	303	320	301	303	313	307	293	267	317	311	291	295	287
March	297	324	300	300	295	291	280	267	285	285	266	273	279
April	276	316	296	269	278	272	255	254	274	271	259	259	257
May	***	***	***	***	***	***	***	***	***	***	***	***	***
June	***	***	***	***	***	***	***	***	***	***	***	***	***
July	***	***	***	***	***	***	***	***	***	***	***	***	***
August	306	297	296	285	267	250	250	257	255	272	247	221	215
September	285	254	279	260	230	231	210	221	192	284	192	201	212
October	361	281	270	258	240	242	197	217	173	324	201	172	214
November	357	363	354	318	338	329	263	341	226	381	265	239	339
December	359	361	362	343	334	330	313	339	340	350	332	319	331

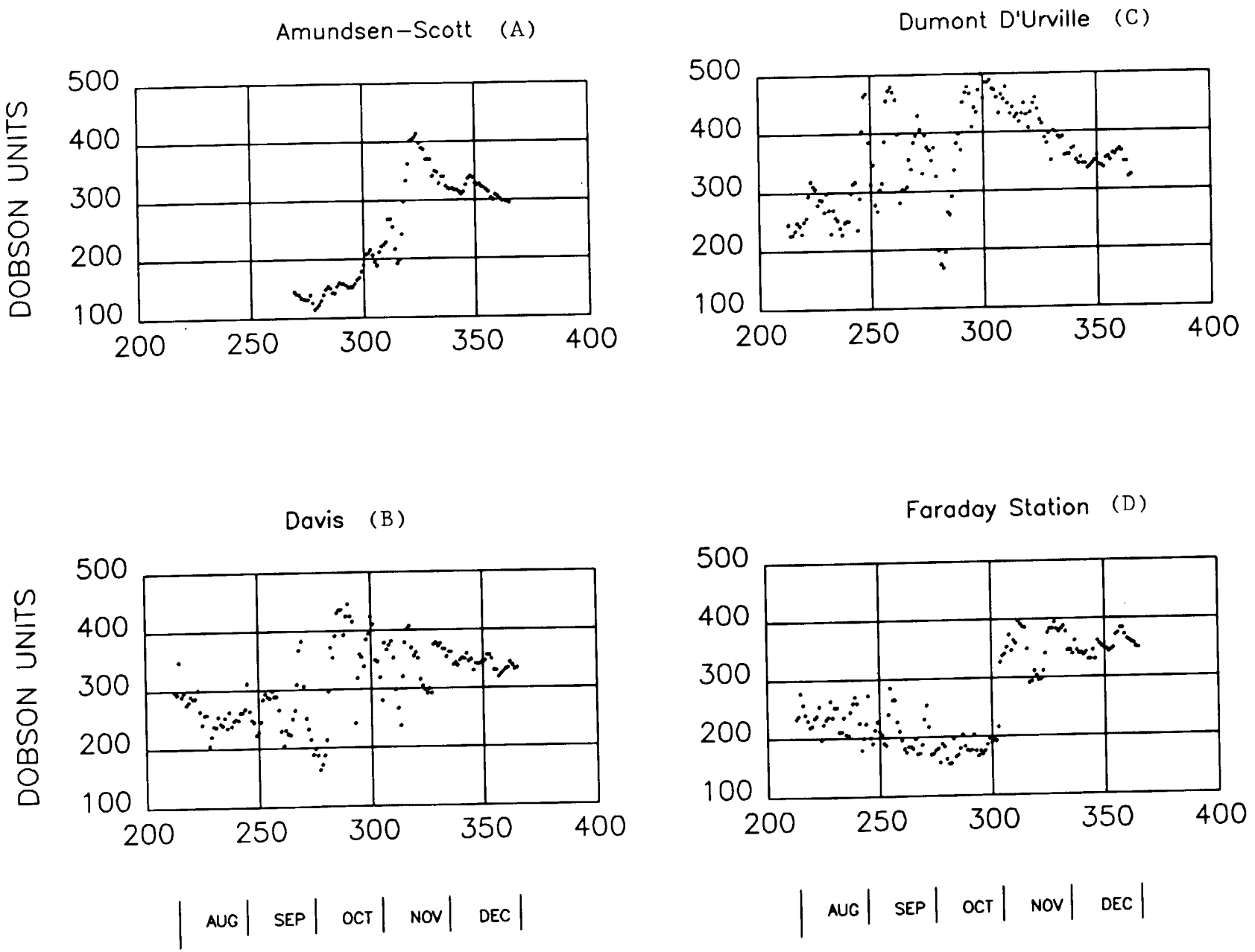

Figure 1A-D. Daily TOMS Total Ozone Values Over Amundsen-Scott, Davis, Dumont D'Urville, and Faraday Station for 1991 (DU).

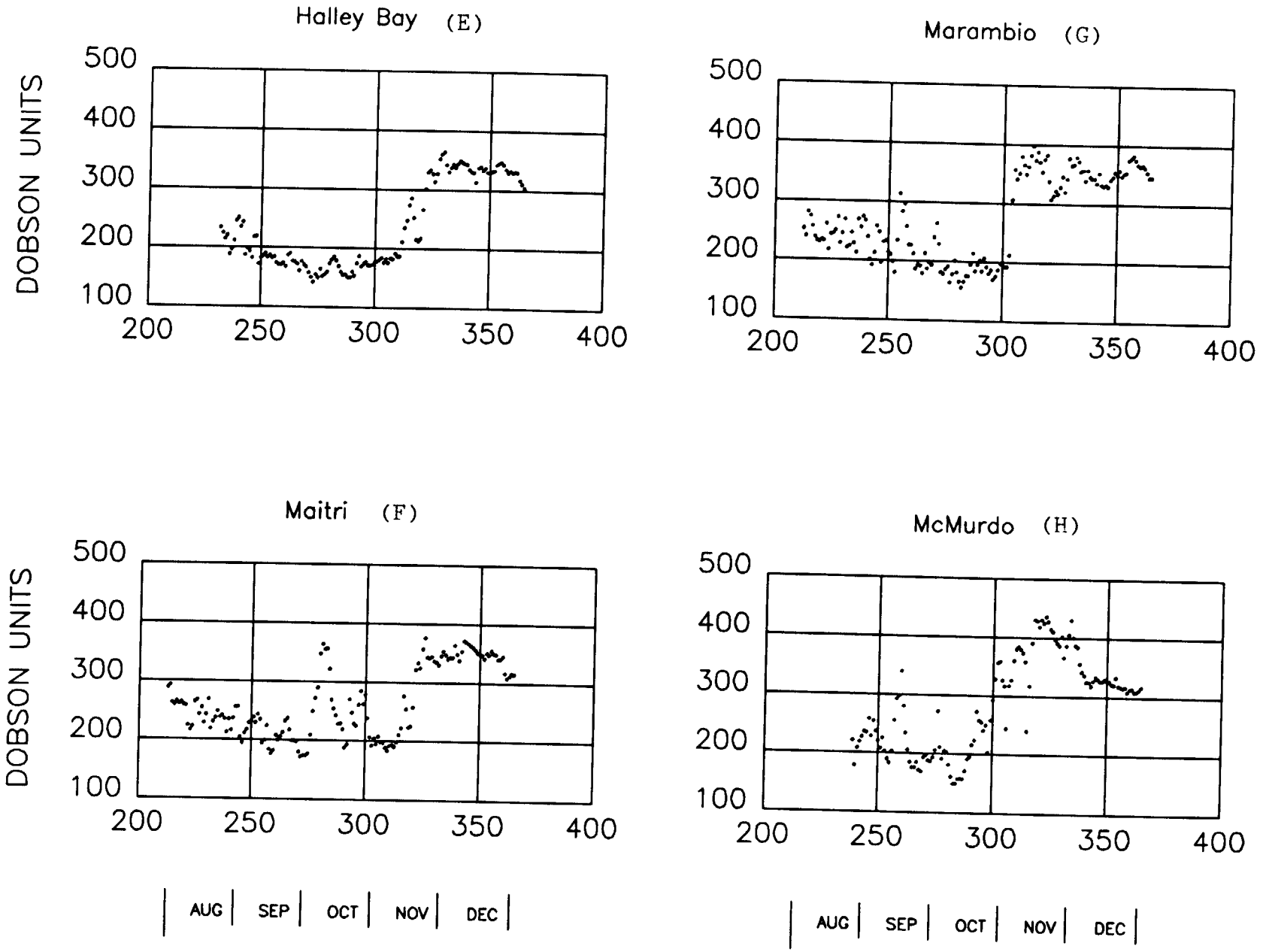

Figure 1E-H. Daily TOMS Total Ozone Values Over Halley Bay, Maitri, Marambio, and McMurdo for 1991 (DU).

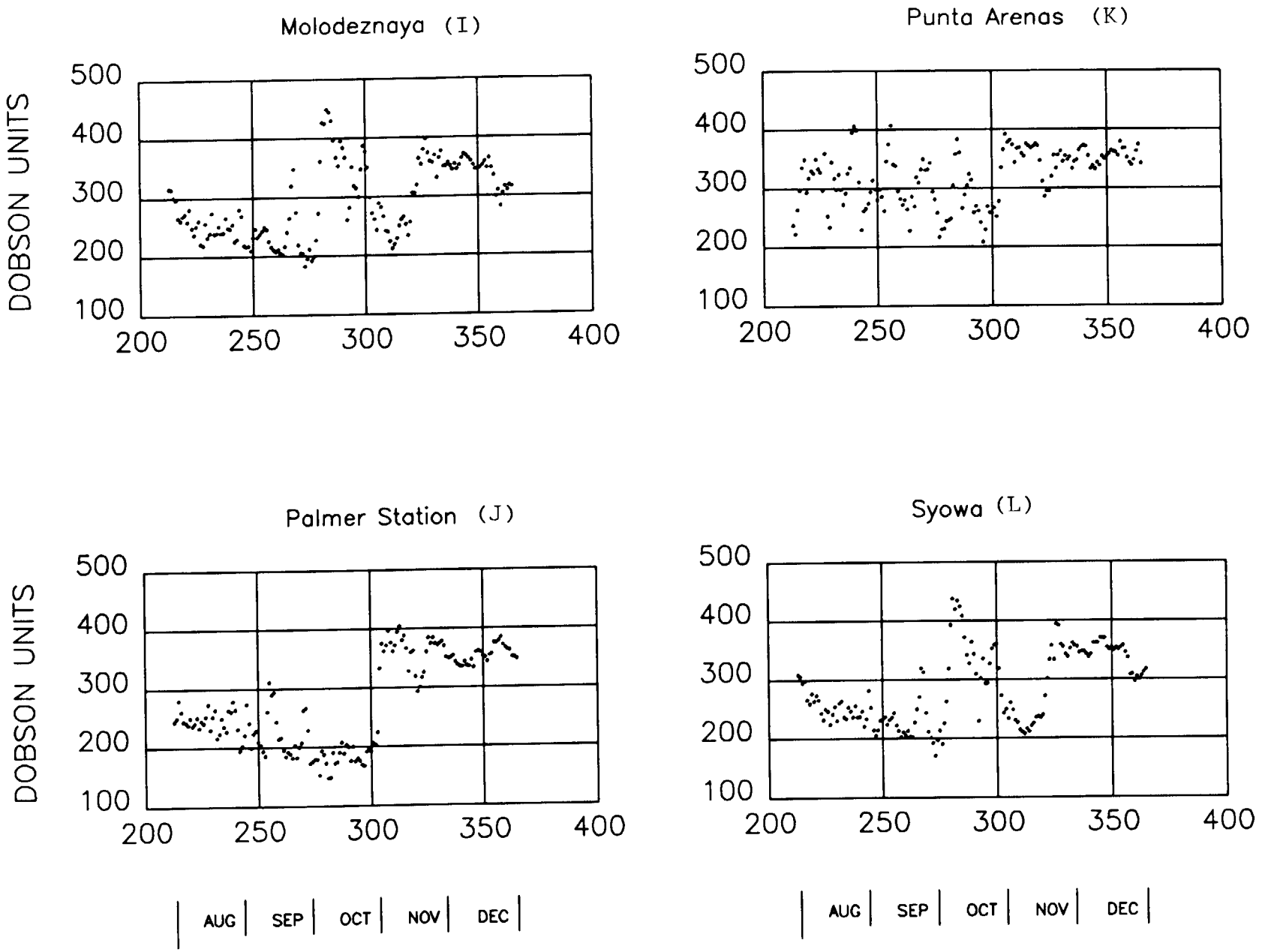

Figure 1I-L. Daily TOMS Total Ozone Values Over Molodeznaya, Palmer, Punta Arenas, and Syowa for 1991 (DU).

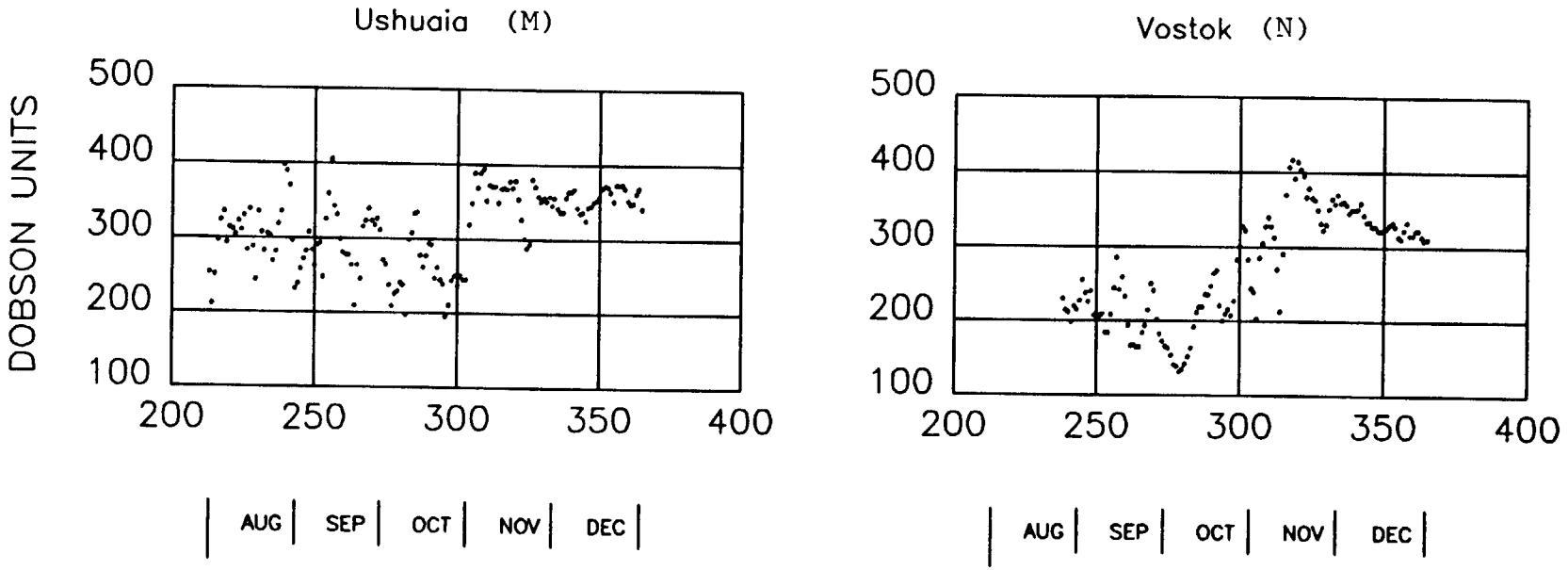

Figure 1M-N. Daily TOMS Total Ozone Values Over Ushuaia and Vostok for 1991 (DU).

3. COMPARISONS WITH PAST OZONE HOLE EVENTS

3.1 Zonal Means

Figure 2A presents a comparison of selected monthly zonal means expressed as a time series over the entire duration of Nimbus-7 TOMS observations. The "-90" time series are for polar observations only. The "-80" and "-70" time series represent 10° bands centered at those latitudes. The southern hemispheric average is a cosine-weighted average for the entire hemisphere. Discontinuities for the three Antarctic means (-90, -80, and -70) are due to a period of total darkness each year when TOMS data are unobtainable.

The observations at 90°S become available in September at their lowest values. These values declined steadily from 1979 through 1987, but have shown no real trend since. The means at 90°S rise rapidly each year to a maximum in December. This maximum has, with the exception of 1988, declined steadily. The mean values for the 80°S band behave much the same way. The 70°S band shows a similar trend in its absolute annual maxima and minima. However, for most of the period, a second, smaller wave is apparent, during or just before the data gap in May through July. This feature seems to have disappeared during the past two seasons. The hemispheric averages show an annual oscillation of fairly constant amplitude, with a very gradual decline in hemispheric total ozone over the period.

Figure 2B shows the mean latitude weighted total ozone for that portion of the Southern Hemisphere south of latitude 70°S for 1979, 1987, 1988, 1990 and 1991 for the period August 1 through November 30. All years show an initial decline, although it is minimal in 1979. Minimum values for 1979 and 1988 occur in September, while the lower minima for 1987, 1990 and 1991 occur very early in October. The years 1979 and 1988 reach a maximum in mid- to late November, while the remaining years rise steadily from early October. The year 1991 is unique in that it remains as low as 1979 and 1988 through mid-October, but then rises rapidly to mirror 1988 by mid-November.

3.2 Monthly Differences

Figures 3A through 3E present the hemispheric differences of monthly mean total ozone between the months of August through December, 1991 and a 4-year reference mean (1979 through 1982). Figures 4F through 4J present the differences of monthly mean total ozone between August through December, 1991 and the same five months in 1987. The year 1987 experienced the most pronounced and long-lived ozone hole to date. Isopleths are solid where the difference is positive, and dashed where it is negative.

During August 1991 (Figure 3A), total ozone is lower than the reference mean at all latitudes south of roughly 50°S. Within this area, the reference mean exceeds August 1991 by as much as 35 percent over the Ross Sea. Over the mid-latitudes and tropics, the total ozone values of August 1991 exceed the reference mean slightly, the maximum difference being 10 percent over the Indian Ocean south of Australia. Negative differences extend furthest from the pole over South America, extending north of 40°S.

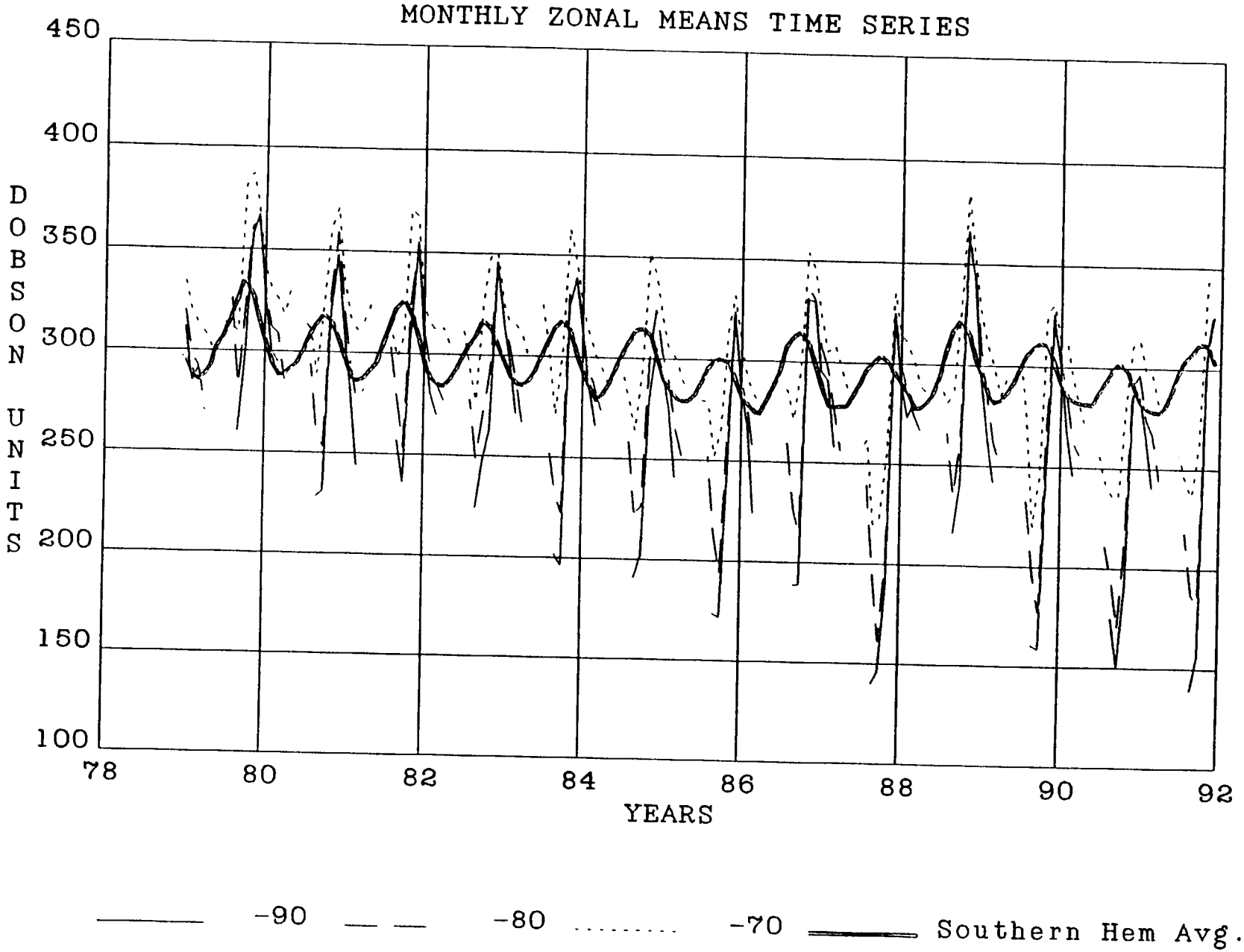

Figure 2A. Selected Monthly Zonal Means for the Southern Hemisphere Expressed as a Time Series Over the Entire Duration of Nimbus-7 TOMS Observations.

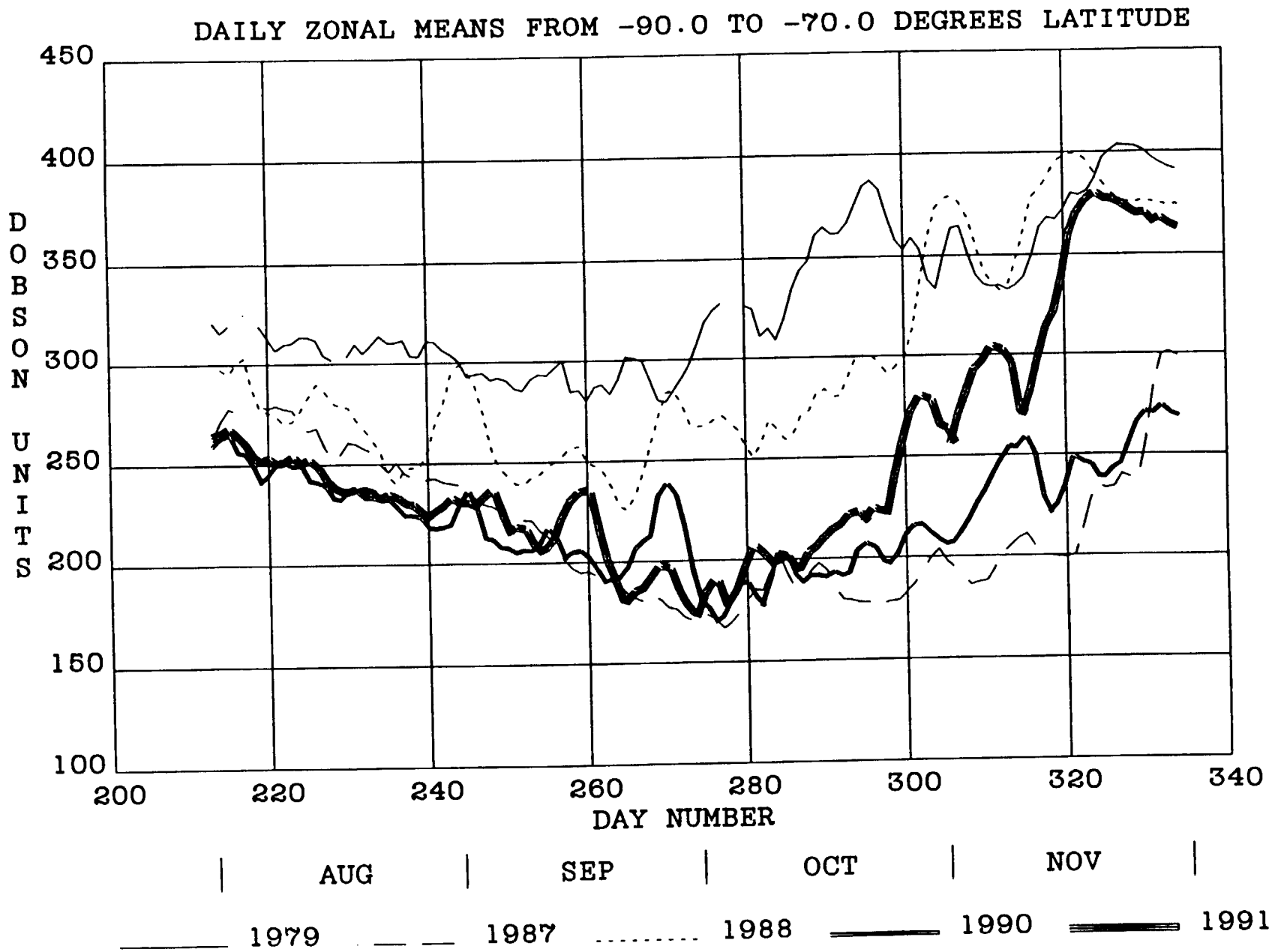

Figure 2B. Mean Total Ozone for the Latitude Band 70°S to 90°S for the Period August 1 through November 30 of the years 1979, 1987, 1988, 1990, and 1991.

During the month of September (Figure 3B), the pattern remains similar. Roughly concentric circles of increasingly negative total ozone differences begin between 50°S and 60°S and extend to the pole, where the reference mean exceeds September 1991 by as much as 40 percent. The negative differences extend further north over South America and adjacent oceans. Slight positive differences exist over the mid-latitudes and tropics, seldom exceeding 5 percent. Total ozone values of the reference mean exceed those of September 1991 in the immediate equatorial regions, in some areas by more than 5 percent.

During October 1991 (Figure 3C), the pattern of negative differences is again skewed toward South America. The total ozone values of the reference mean exceed those of October 1991 by 40 percent near the tip of the Antarctic Peninsula. Slight positive differences exist over most of the mid-latitudes and tropics, although slight negative differences recur near the equator. Differences north of 60°S are largely due to the orientation and size of the ozone hole.

Figure 3D presents evidence of the rapid filling of the 1991 ozone hole. Total ozone values for November 1991 exceed the reference mean over most of the hemisphere. Only over Queen Maude Land and the adjacent Atlantic and Indian Oceans do negative differences persist.

During the month of December, 1991 (Figure 3E), the pattern is very flat, with slight negative differences in the polar regions, and slight positive differences elsewhere.

In comparing August 1991 to August 1987 (Figure 3F) one finds total ozone values lower in 1991 over polar regions within 60°S extending northward over South America and the adjacent Pacific Ocean. Maximum differences over Antarctica exceed 15 percent. The values for 1991 exceed those of 1987 over the remainder of the hemisphere, reaching maximum differences exceeding 20 percent over the Indian Ocean south of Australia.

During the month of September (Figure 3G), total ozone values for 1991 again exceed those of 1987 over a large part of the hemisphere. The maximum positive differences are over the coast of Wilkes Land, a region which saw the frequent passage of large ozone maxima in 1991. Differences here exceed 40 percent in places. Total ozone values for 1991 were lower than 1987 only in polar regions adjacent to the southeast Pacific and South Atlantic, with maximum differences of 15 percent. Some evidence of slight equatorial ozone decreases are also evident.

During October 1991 (Figure 3H), total ozone values for 1991 again exceed those of 1987 over most of the hemisphere, and especially over most of the Antarctic continent. Positive differences exceed 50 percent near the Indian Ocean coast of Queen Maude Land. Only over the Antarctic Peninsula are continental values lower in 1991. Negative differences extend over South America and the adjacent ocean areas, with maximum differences of 25 percent over the Drake Passage. Again, slight negative differences are seen over the immediate equatorial regions.

The 1991 ozone hole filled much sooner than the long-lived 1987 event. Figure 3I shows dramatically the higher total ozone values of 1991. Positive differences exceeding 70 percent occur near the pole. Only a small area off the coast of Queen Maude Land, the last location of the 1991 ozone hole shows negative differences.

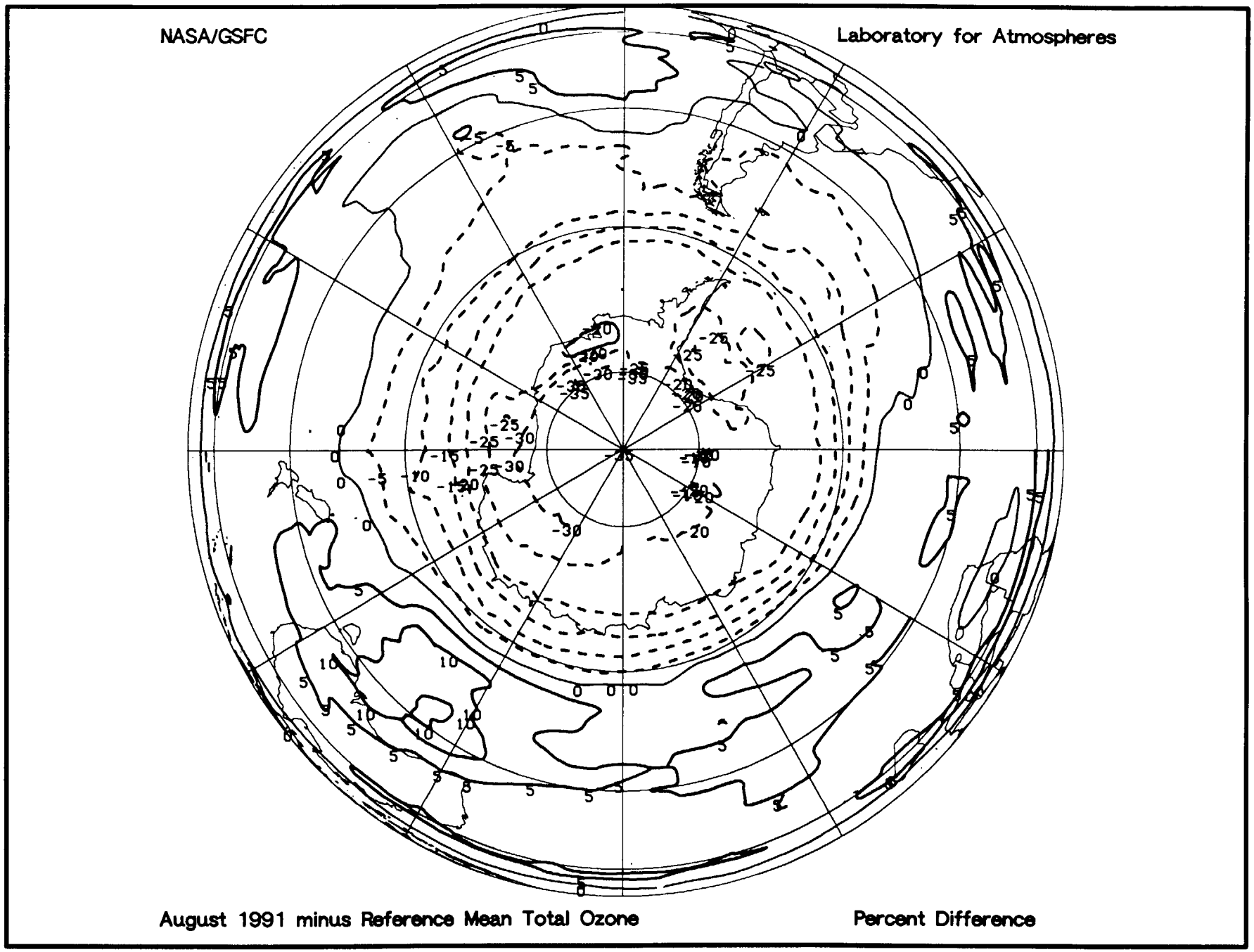

Figure 3A. Monthly Mean Total Ozone Difference Between August 1991 and a 4-Year Reference Mean (August 1979 through 1982).

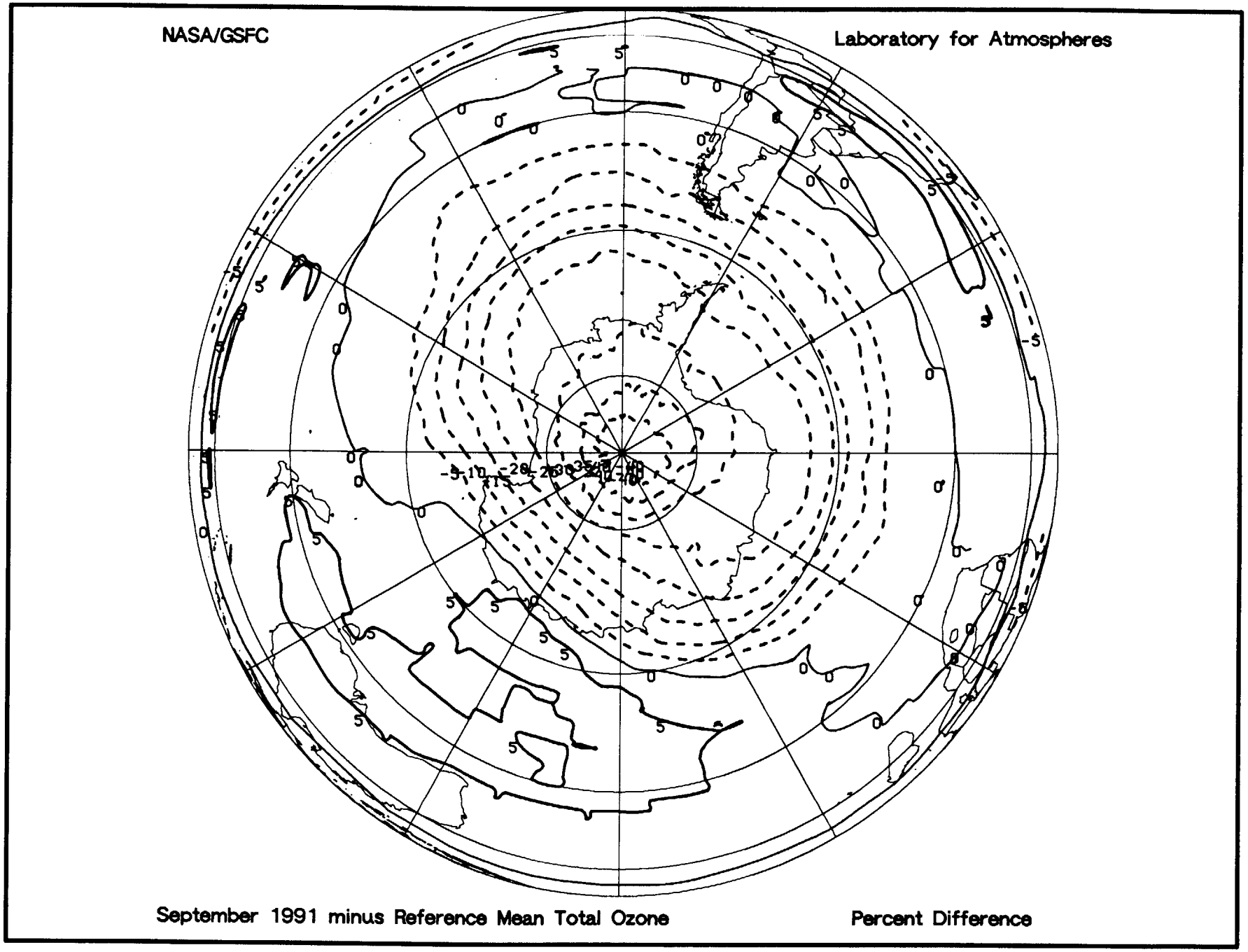

Figure 3B. Montly Mean Total Ozone Difference Between September 1991 and a 4-Year Reference Mean (September 1979 through 1982).

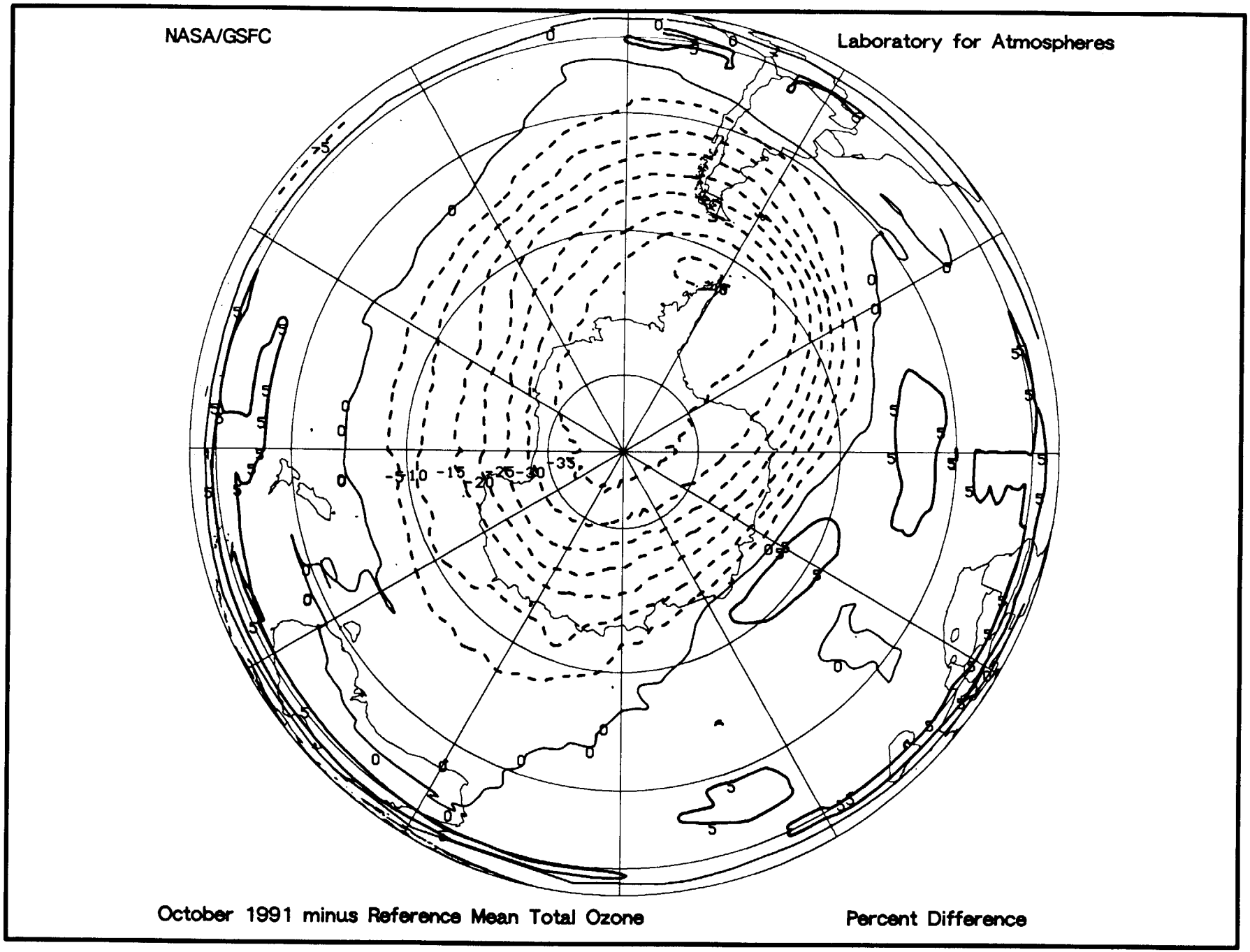

Figure 3C. Monthly Mean Total Ozone Difference Between October 1991 and a 4-Year Reference Mean (October 1979 through 1982).

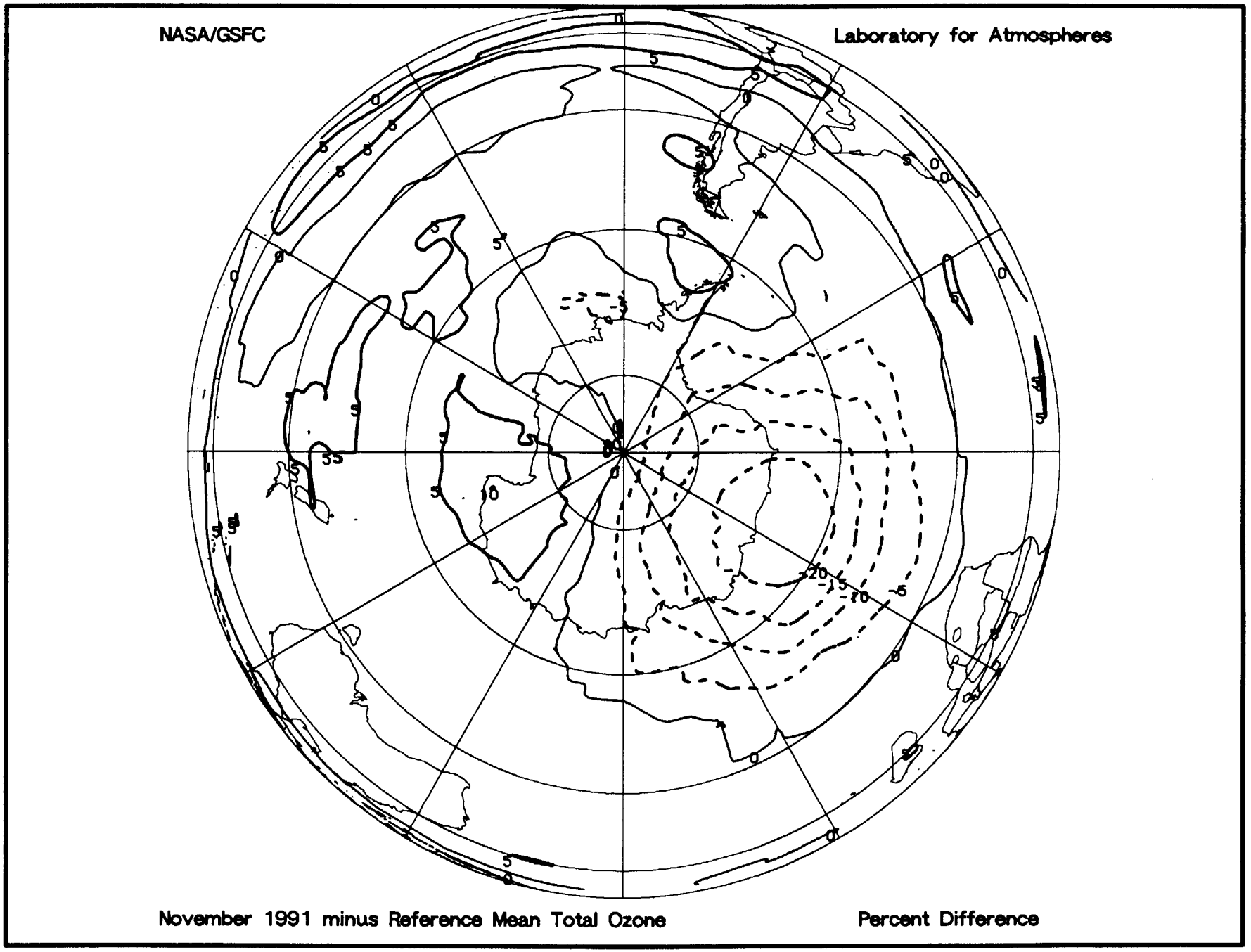

Figure 3D. Monthly Mean Total Ozone Difference Between November 1991 and a 4-Year Reference Mean (November 1979 through 1982).

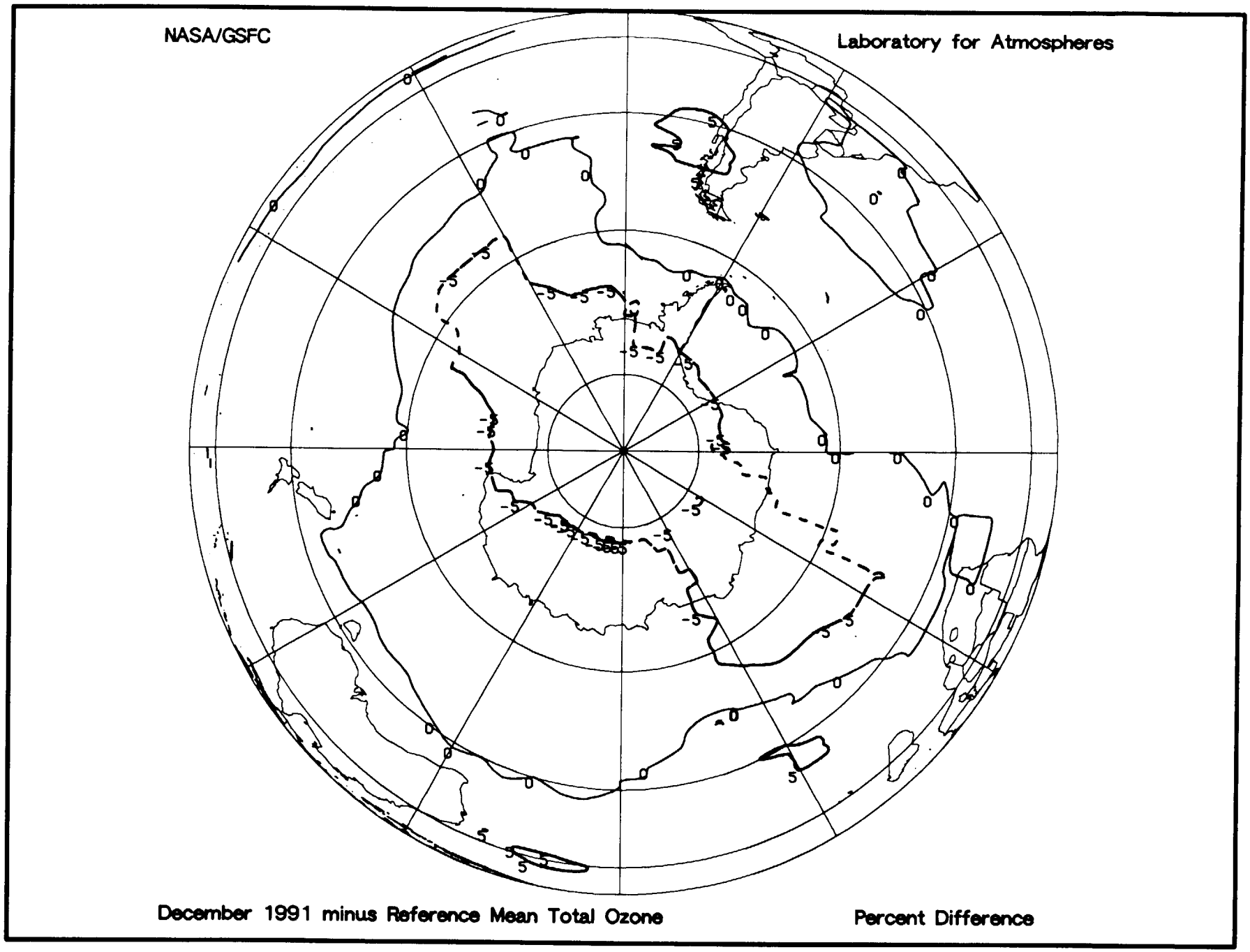

Figure 3E. Monthly Mean Total Ozone Difference Between December 1991 and a 4-Year Reference Mean (December 1979 through 1982).

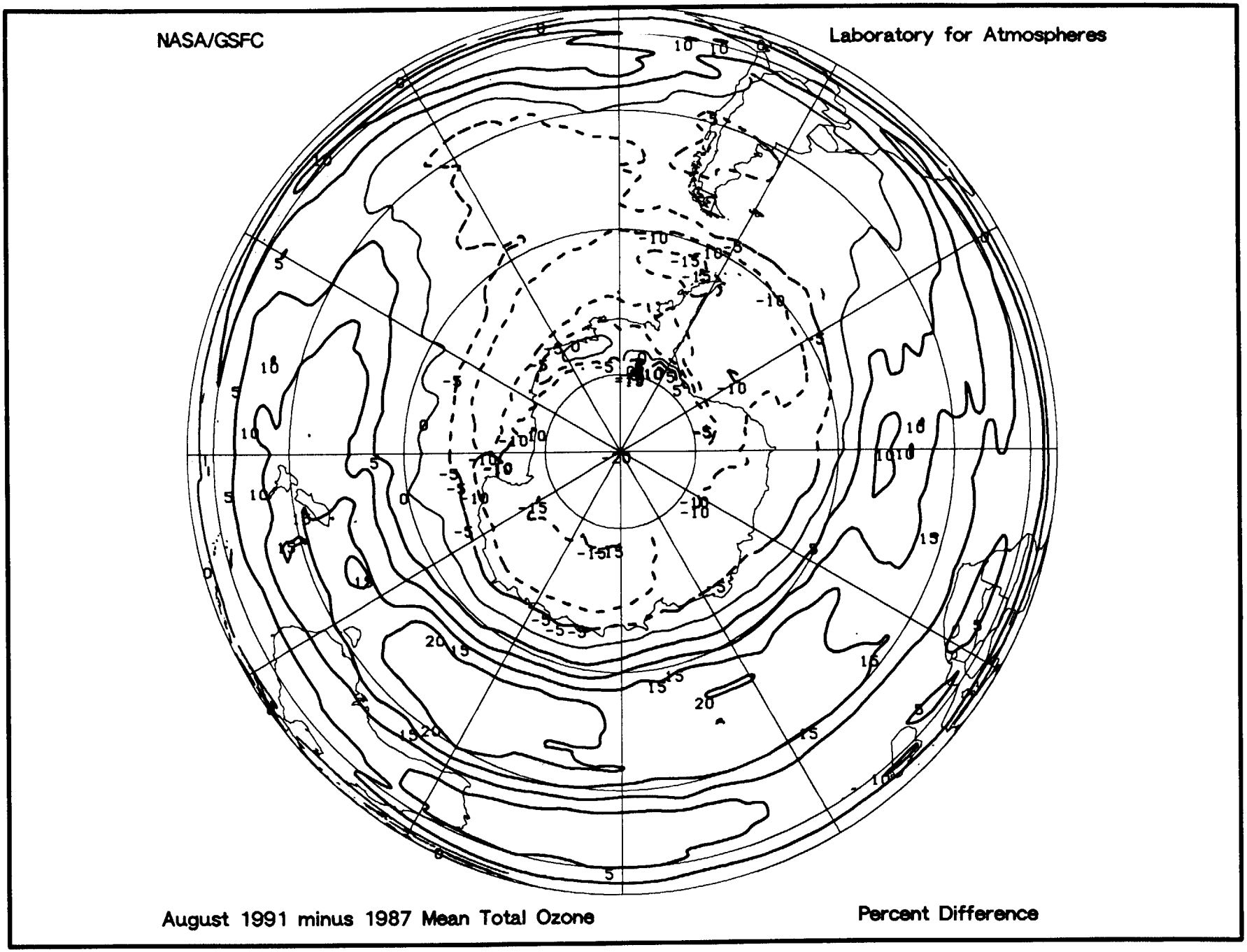

Figure 3F. Monthly Mean Total Ozone Difference Between August 1991 and August 1987.

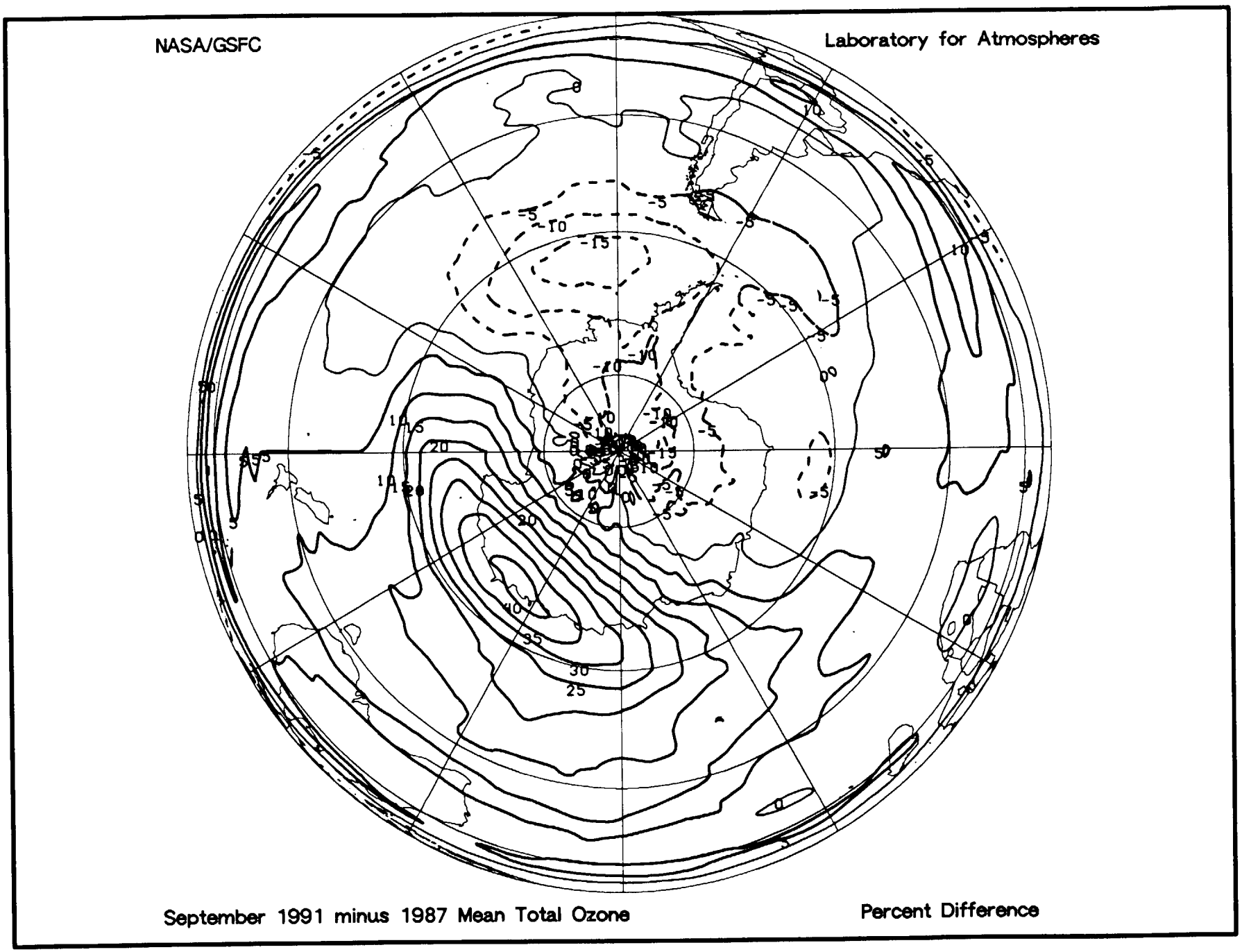

Figure 3G. Monthly Mean Total Ozone Difference Between September 1991 and September 1987.

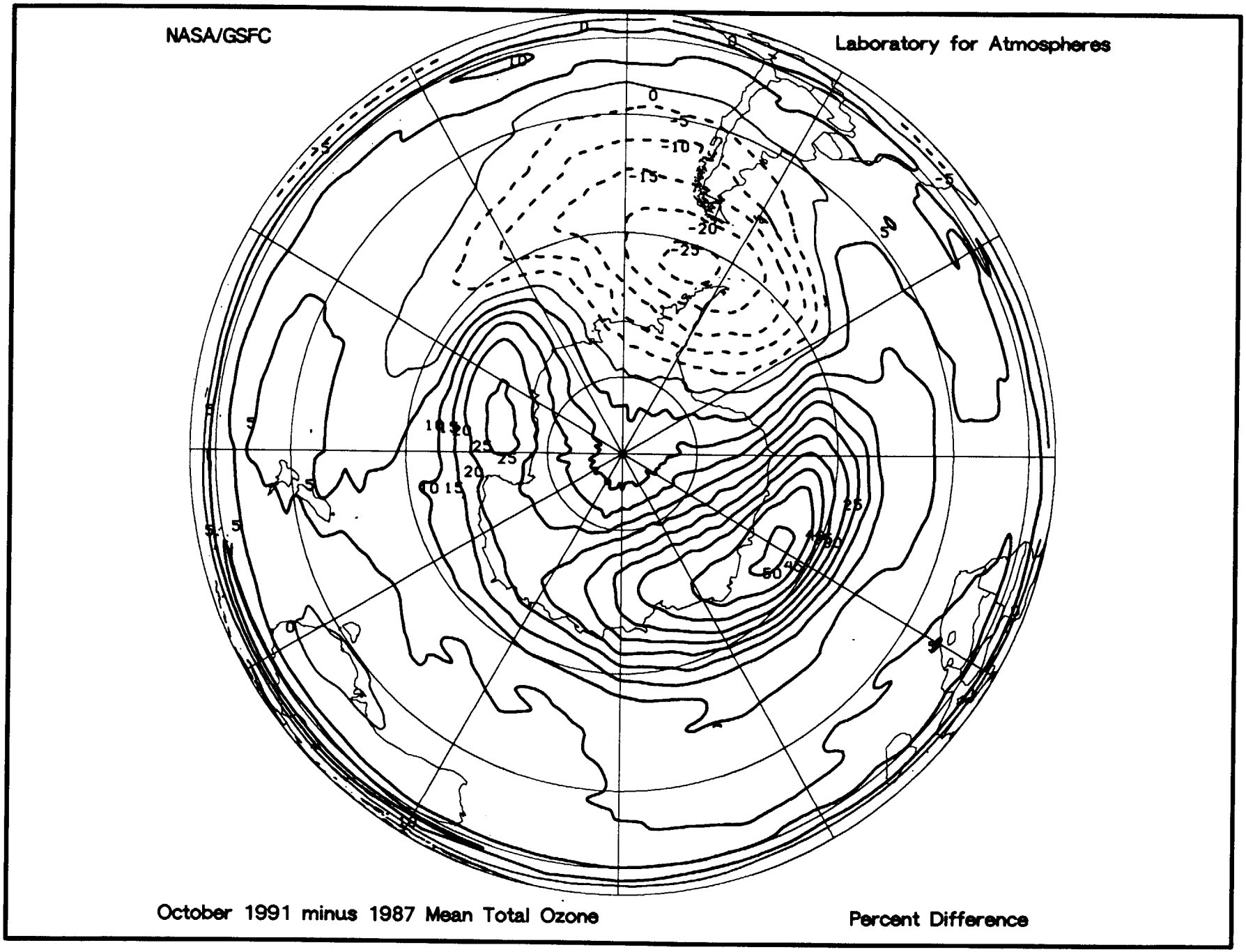

Figure 3H. Monthly Mean Total Ozone Difference Between October 1991 and October 1987.

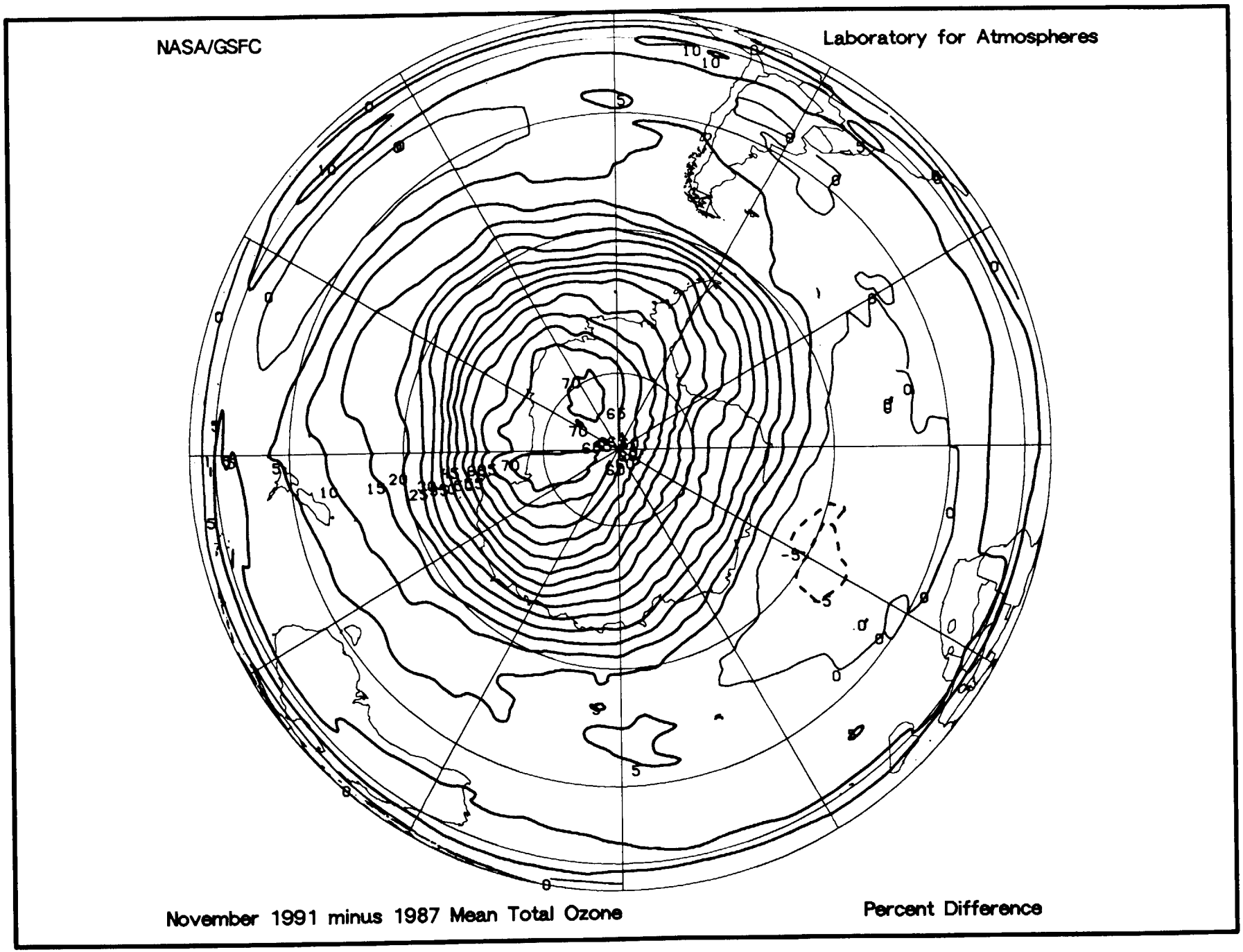

Figure 3I. Monthly Mean Total Ozone Difference Between November 1991 and November 1987.

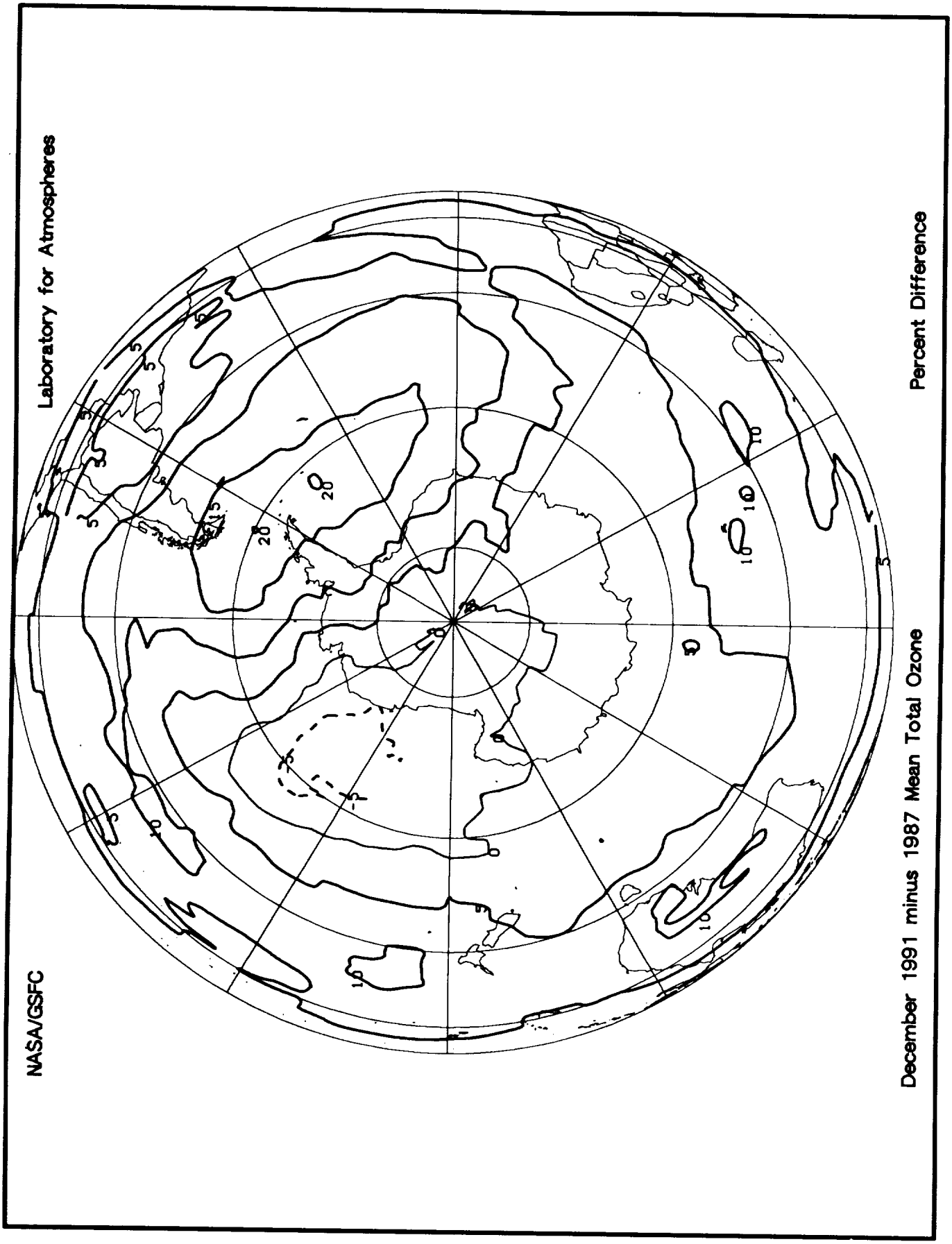

Figure 3J. Monthly Mean Total Ozone Difference Between December 1991 and December 1987.

During December 1991 (Figure 3J), total ozone values are still significantly higher than in 1987. Positive differences exceed 10 percent over a large portion of the hemisphere. A very small area of negative differences exist over the South Pacific.

3.3 Comparisons of Daily Minima

Figure 4 presents the daily minimum total ozone values over that portion of the Southern Hemisphere south of latitude 60°S for the period August through December of the years 1979, 1987, 1988, 1989, 1990 and 1991.

Prior to early September, there is significant day-to-day variation within all years, and little coherent pattern. The absolute lowest values during this period were in 1988 and occurred in the many significant mini-holes which developed that year. These were, in fact, the lowest values of 1988, exceeding in depth the mature ozone hole.

As we progress through September and October, a stable pattern develops. The minimum values for 1979 are significantly higher than those of the other 5 years, remaining above 200 DU. The values for 1987, 1989, 1990 and 1991 are clustered together, reaching minimum values below 130 DU in early October. The absolute minimum for 1991 is the lowest of all. The values for 1988 are midway between those of the clustered years and 1979.

As we approach early November, the values for 1979 and 1988 merge at a level considerably higher than the remaining years. By mid-November, the values for 1991 leave the 4-year cluster and rise rapidly. By the end of December, all 6 years tend to converge at about 300 DU.

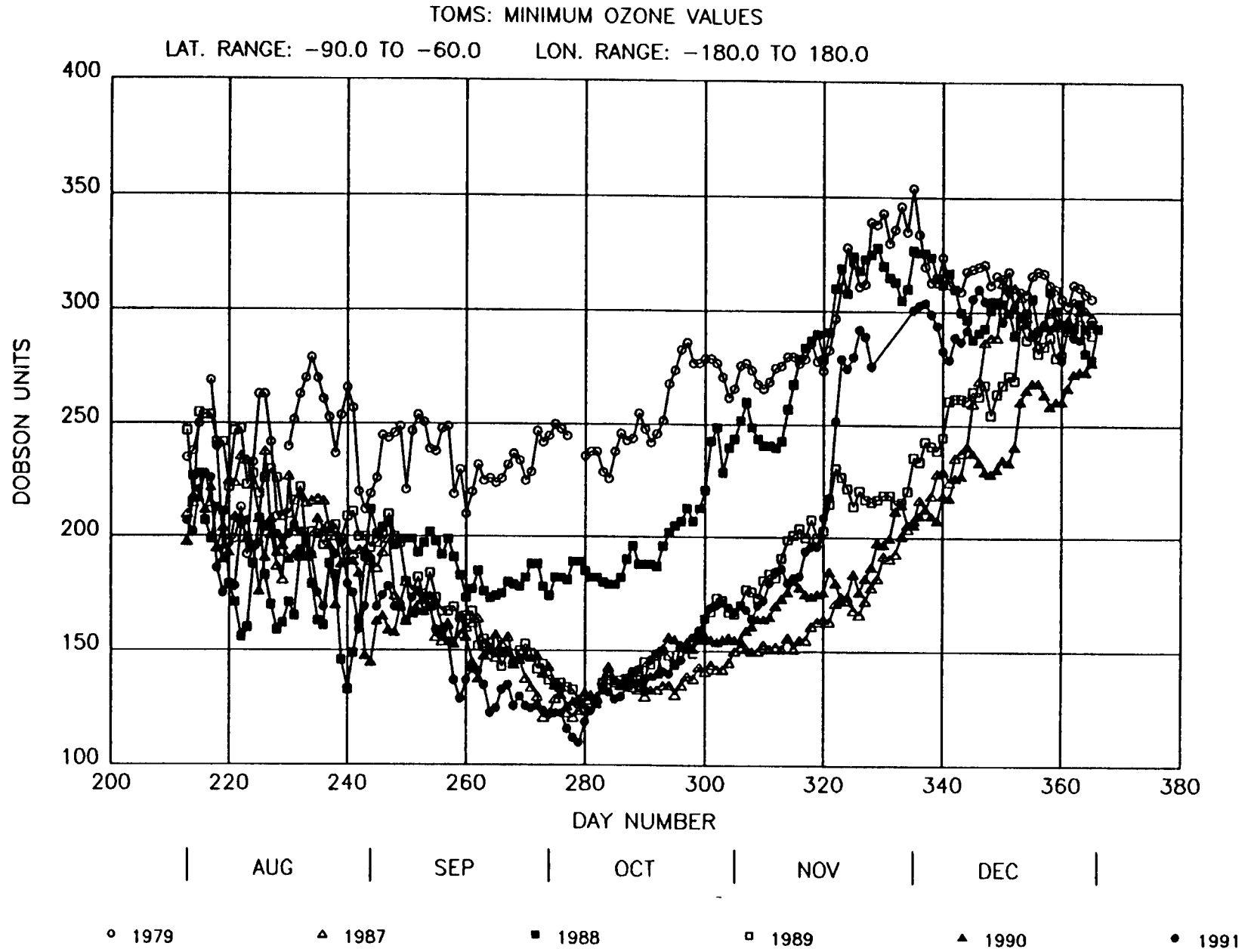

Figure 4. Daily Southern Hemisphere Ozone Minimum for the Period August 1 through December 31 of the Years 1979, 1987, 1988, 1990, and 1991.

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